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HELICOPTER EXTERNAL LOAD ACQUISITION TECHNOLOGY INVESTIGATION

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Post Office Box 482
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Final Report

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U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report documents a comprehensive investigation of helicopter external load acquisition technology, addressing primarily the problems of improving the acquisition of prerigged sling and/or netted loads under poor visibility and other hazardous conditions. Promising external load acquisition concepts and improvements to present systems were identified and evaluated. The data and conclusions presented herein will provide the basis for the Army's selection of the best technical approach for further developmental effort.

Richard E. Lane of the Aeronautical Systems Division was the project engineer for this effort.

Unclassified

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The purpose of this study was to identify, analyze, and evaluate methods of improving the acquisition of sling and/or netted loads by a hovering helicopter under poor visibility and other hazardous conditions. Flight and ground crew tasks required to support the external cargo operations were analyzed and resulting baseline crew workloads defined. Hazard analyses of the mission phases were accomplished and hazard categories identified.

20. Continued

The results of these analyses were then used as criteria for selecting potential concept candidates for improvement in external load acquisition. Ten candidate concepts were identified. Each was evaluated against established baselines and then ranked in order of improvement over the baseline concept.

PREFACE

To determine and verify external load tasks, problems, and potential solutions, assistance was provided by the following organizations and is gratefully acknowledged:

136th Aviation Company (T.C.), Texas
Army National Guard, Dallas, Texas

158th and 159th Aviation Battalions
101st Airborne Division, Fort Campbell, Ky.

Evergreen Helicopters, McMinnville, Oregon

The Army Technical Representative for the program was Mr. Richard E. Lane. His guidance and assistance is gratefully acknowledged.

The following Bell Helicopter Textron personnel contributed to this program:

Dr. Dora Strother	- Chief of Human Factors
Mr. Michael J. Carnevale	- System Safety Engineer
Mr. Hal L. Hiner	- System Safety Engineer
Mr. Robert R. Taylor	- Design Engineer

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INTRODUCTION

BACKGROUND

This report presents the results of a study by Bell Helicopter Textron to investigate helicopter external load acquisition technology.

Helicopter movement of cargo externally has grown rapidly over the past years. Prior to Vietnam, only moderate emphasis was placed on external load operations. During the Vietnam conflict, external carriage increased to a point where 75 percent of all cargo was carried externally.

Equipment and procedures presently being used for handling helicopter external loads evolved from the need to meet unique demands as they arose. At that time, little consideration was given to overall external load operations. The current hookup procedure generally requires a ground crewman positioned underneath the helicopter to manually attach the load. This procedure is slow and the ground crewman is subjected to a dangerous environment.

Current Army tactical doctrine[1] emphasizes that utility and medium helicopters be capable of carrying external loads around the clock and in instrument meteorological conditions (IMC), using terrain flying techniques. The effectiveness of the external load mission is directly related to the interface between the load and the aircraft. During visual meteorological conditions (VMC), the acquisition process is difficult. Under reduced visibility conditions, the process rapidly becomes a hazardous operation and seriously compromises mission effectiveness. External load operations in IMC is beyond the capability of the present-generation helicopters.

The objective of this study was to identify, analyze, and evaluate methods of improving the acquisition of cargo by a hovering helicopter under poor visibility and other hazardous conditions.

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1. EMPLOYMENT OF ARMY AVIATION UNITS IN A HIGH THREAT ENVIRONMENT, Field Manual 90-1, Headquarters, Department of the Army, Washington, D. C., 30 September 1976.

TECHNICAL APPROACH

The external load study was divided into two separate phases of activity. Phase I dealt with identification and analysis of current equipment, tasks, and procedures. This process of identifying and analyzing helicopter, ground crew, and flight crew tasks started with a definition of the scope of the missions involved. From these missions, crew tasks were defined. Human Factors Engineering (HFE) analyses were then performed, which resulted in detailed task descriptions. These analyses showed the interaction of flight and ground crews operating within the constraints placed on them by helicopter performance capabilities and limitations of selected missions. From these analyses, an index of workload was determined as well as crew information requirements. Special emphasis was placed on weather conditions and visibility restrictions that occur during acquisition operations. In addition, a hazard analysis was performed using MIL-STD-882A as a guide.

Phase II consisted of survey and technology searches to identify alternative technical and/or procedural candidates that exhibited potential for improvement of the load acquisition and delivery process. These alternative candidates were ranked in order of improvement over the baseline data developed in Phase I.

PHASE I

HUMAN FACTORS ENGINEERING ANALYSIS

The analysis and identification process made use of human factors engineering (HFE) procedures to describe in detail the series of activities that the flight and ground crews would experience in a typical Army external load mission in existing helicopters. Factors used to determine the level of detail to be analyzed for various mission phases were: (1) applicability to external load acquisition, and (2) availability of data. Related to this approach was the determination of "time available" versus "time required" that would form baseline norms or standards.

The HFE analysis was conducted in the following steps:

- Define the mission and divide into several phases of crew activity.
- Define airborne and ground equipment involved in external load acquisition.
- Detail flight and ground crew tasks.
- Determine workload distributions

Mission Definition

The mission as defined by the Army consists of the transport of externally suspended loads by utility (UH-1H and UH-60) and medium lift (CH-47) helicopters. The external load missions would be both logistical and tactical. Operations would be conducted day and night during all types of weather and operating conditions.

Mission Scenario. The study mission depicts a helicopter dispatched to a designated pickup zone (PZ) to pick up and transport a pre-rigged sling load to another designated drop zone (DZ) and return.

For purposes of this analysis, it was assumed that this mission would be conducted during daylight in visual meteorological conditions. It was also assumed that a normal flight crew of two rated pilots would be in the cockpit and at least one crew chief would be on board. Current established practices of crew coordination and division of duties would be exercised. A trained ground crew of three would be present in the PZ and in the DZ. The load would be pre-rigged and

designated. Normal voice security procedures would be enforced. Cruise to the PZ, as well as transport of the load, would be flown using terrain flying techniques.[2] Both the PZ and DZ would be large enough to prohibit any abnormal constraints on maneuvering for hookup or release of load. Approach and departure paths would be unrestricted.

Mission Phases. The study mission was divided into several phases of crew activity. These phases are briefly discussed in the following paragraphs.

- Cruise to Pickup. This phase consists of the crew activities concerned with planning, navigating, and maneuvering the helicopter to the PZ area.

- Approach for Pickup. As the PZ is identified and direction of approach determined, the descent is initiated. The ground crew and load are located. The descent continues until all barriers are cleared and is terminated at a hover. The final portion of the descent is directed by the ground signalman.

- Hookup. At hover, the flight crew follows the ground signalman's directions to the load. (Note: Primarily, the CH-47 uses instructions from the crew chief for maneuvering in the PZ.) When the helicopter is hovering directly over the load, the apex fitting (donut) is attached to the external hook by a ground crew member (note that prior to attachment, the static charge on the hook is discharged by the third ground crew member). After hookup, the ground hookup crew clears the area under the aircraft. The helicopter is then centered over the load and proceeds upward to lift the load. Once the load is off the ground, the aircraft is prepared for departure.

- Departure with Load. After the takeoff (TO) is complete, a climb at maximum power is initiated to clear any departure barriers. Once the barriers are cleared and planned altitude is reached, level flight is established.

- Transport Load. The load is then carried to the DZ using terrain flying. This phase has been thoroughly analyzed, problems identified, and solutions recommended, and will not be analyzed in this report.

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2. TERRAIN FLYING, Field Manual 1-1, Headquarters, Department of the Army, Washington, D. C., 1 October 1975.

- Approach with Load. This phase concerns initiating the descent into the DZ. An angle of descent is established that will clear the load of any barriers to the DZ. This phase is completed with the termination of descent at a high hover, with the load 5 to 10 feet off the ground, and within the performance limits of the helicopter.

- Release Load. This phase is the completion of the hookup. It starts with the helicopter at high hover in the DZ and maneuvering the load to the designated spot, the load is lowered to the ground, and the helicopter continues downward until the slings/straps/ cables are slack. The load is then released and the helicopter moves into takeoff position and completes the pre-takeoff check list.

- Departure After Load Release. Departure starts with the addition of thrust and climb-out initiation. The climb-out continues until cruise altitude is reached and level off attained.

- Cruise to Home Base. After departure and level off from the DZ, the final phase consists of navigation and operation of the aircraft back to home base.

A top-level mission phase flow diagram is shown in Figure 1. The top-level diagram was further subdivided into phase segments for detailed analysis. Second-level mission phase segments are shown in Appendix A.

External Load Equipment

Airborne Equipment Definition. Airborne external cargo equipment for all current helicopters utilize some form of single-point load suspension. To improve transport of low-density loads, the CH-47D has been modified to a dual tandem hook in addition to the conventional single-point hook. The load suspension equipment of the CH-47, UH-60 and UH-1 are briefly discussed in the following paragraphs.

The position of the CH-47 center cargo hook is such that the load is suspended beneath the center of gravity of the helicopter. The hook assembly consists of a cargo hook, hydraulic actuator, and a carriage equipped with rollers. The hook is suspended by means of the carriage from a removable beam that is mounted inside the rescue hatch. This beam is curved and rotates within its mounting supports to minimize the effects of a shifting load on helicopter stability. Stops mounted near both ends of the beam prevent the moving carriage from damaging the surrounding structure. The cargo

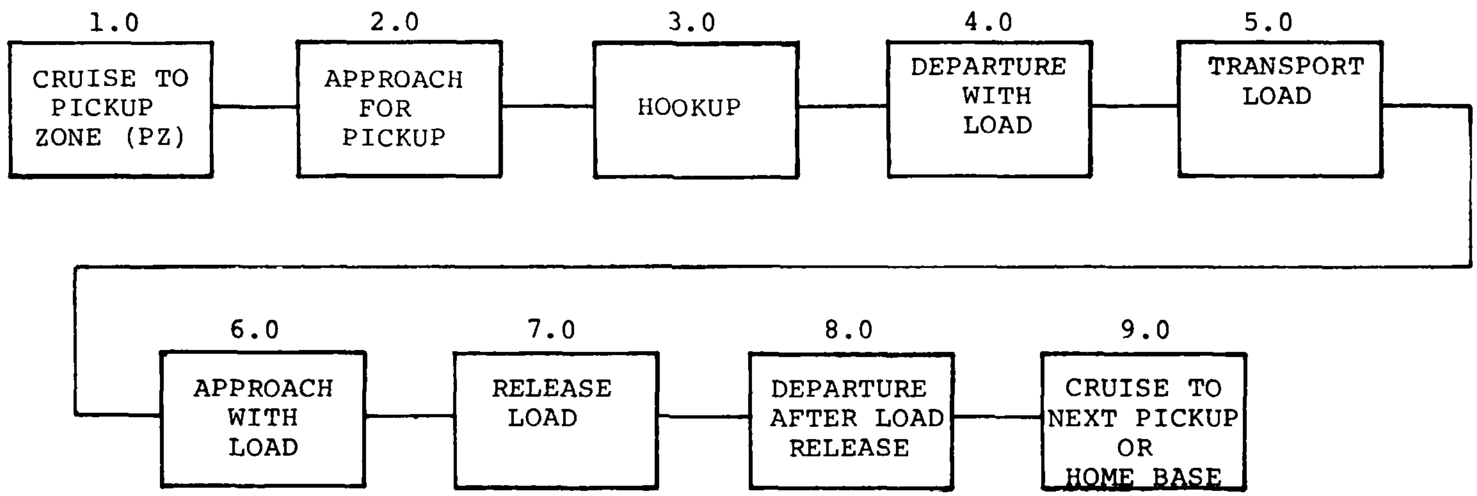

Figure 1. Mission phase.

hook system is normally operated hydraulically by pressure from the utility hydraulic system. In the event of a loss in utility system pressure, the cargo hook can be opened pneumatically or manually. The cargo hook contains a spring-tensioned keeper that prevents accidental loss of cargo through slippage of the sling rings.

The UH-60 cargo hook system consists of a hook assembly mounted on the lower fuselage, a control panel on the upper console, a normal release button on each control panel on the upper console, a normal release button on each cyclic stick grip, one emergency release switch on each collective stick grip, and a firing key in the cabin for use by the crew chief. The hook capacity is limited to a maximum of 7000 pounds, at a load factor of 2.5g, and has a throat and load beam of adequate area and configuration to accommodate load attachments with nylon slings. The system incorporates three modes of load release: an electrical circuit actuated from the cockpit, a manual release worked by the crew chief through a covered hatch in the cabin floor or by personnel on the ground, and an emergency release system utilizing an electrically activated explosive charge.

The UH-1H external cargo consists of a short single-cable suspension unit secured to the primary structure at the approximate center of gravity. A manual cargo release push pedal is located between the pilot tail rotor control pedals, and an electrical release pushbutton switch is located on the cyclic control stick. Before the electrical release switch on the cyclic control stick can be actuated, the CARGO RELEASE switch on the overhead panel must be positioned to ARM. Three cable and spring attachments keep the unit centered and the hook protrudes slightly below the lower surface of the helicopter. A rear view mirror, available on some models, enables the pilot to visually check operation of the external cargo suspension hook.

Table 1 lists the current airborne equipment for each helicopter.

Ground Equipment. Ground equipment primarily considered for this study included slings and nets. The nylon chain multiple-leg sling is the most common sling assembly currently in use. A sling set consists of four nylon web and chain legs, with a nylon web ring (commonly known as the "donut") holding the four legs together. The sling set has a capacity of 15,000 pounds and is approximately 23 feet long overall. Due to rough handling and lack of valid inspection procedures, the

TABLE 1. AIRBORNE EXTERNAL LOAD EQUIPMENT

SYSTEMS	UH-1H	UH-60	CH-47
1. External suspension system.	One 4000 lb hook	One 8000 lb hook	(A,B,C) One 16,000 to 20,000-lb hook (D) Three hooks, one 28,000-lb, two 20,000-lb
2. Normal release system	Electrically initiated by pilot or copilot. Hook electrically actuated.	Electrically initiated by pilot or copilot. Hook electrically actuated.	Electrically initiated by pilot, copilot or crew chief. Hook is actuated by hydraulic pressure. ("D" model) fore and aft hooks are electrically actuated.
3. Emergency release system	(a) Manual release by pedal between pilot's control pedals (b) Manual release opened by ground personnel	(a) Electrical explosive charge initiated by pilot, copilot, or crew chief. (b) Manual release on hook actuated by either crew chief or ground personnel.	(a) Compressed air chg initiated by pilot or crew chief (b) Manual release by crew chief ("D" model has no manual release)
4. Cockpit indication system	"Cargo Release" light is lit when release switch is in "Arm" position.	(a) "Hook Armed" light is lit when cargo switch is in "Armed" position. (b) "Cargo Hook Open" light lit when hook load arm is released.	"Cargo Hook Open" light is lit when hook is released.
5. Acquisition provisions	Mirror on nose of helicopter	Small hatc'. above hook	(a) Rescue hatch above center cargo hook. (b) Cargo pole for sling acquisition by crew chief.

nylon slings are subject to premature failures. In Vietnam, slings were the most significant cause of failure of external cargo systems.[3]

There are currently three types and sizes of nets in use. The standard cargo net has a capacity of 8930 pounds, measures 14 feet across each side, and weighs 50 pounds. The 5000-pound and 10,000-pound capacity nets are new and add versatility in external loading. Estimations of external cargo loads in Vietnam[3] indicated that 33 percent of all cargo was transported in nets.

New Equipment Developments. Several new equipment programs are undergoing research, design, and development at the present time. The programs applicable to this external load equipment study are:

- Advanced Technology Sling Legs. To improve external cargo slings, a design and development program of a lightweight cargo sling made of Kevlar[4] is currently in progress. Kevlar is very durable, lightweight, and should provide easier rigging for ground crews.

- Kevlar Sling Apex Fittings. To further improve the ease of ground crew rigging and complement the new Kevlar sling legs, apex fittings made of Kevlar are being tested and evaluated. The Kevlar apex fittings are lightweight (less than one pound) yet capable of carrying the full load of the Kevlar sling legs.

Task Analysis

Task analysis involves a detailed definition of the functions of the operator (flight and ground crews in this study) and the information transferred between them. From the mission phases and segments, those tasks directly involved with load acquisition and release were selected for detailed flight crew and ground crew task analysis.

---

3. Hunt, R. E., FAILURE ANALYSIS OF HELICOPTER EXTERNAL CARGO-HANDLING SYSTEMS, Arthur D. Little, Inc., USAAMRDL Report 73-44, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1973, AD 767254.

4. Scala, E., DESIGN AND DEVELOPMENT OF HELICOPTER EXTERNAL CARGO SLING LEGS MADE WITH KEVLAR; Cortland Line Company, USARTL Report 78-20, Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, June 1978, AD A047560.

Data Collection. To obtain information on sling and netted load missions and crew tasks as performed by current Army units during combat training missions, data collection trips were made to:

- The 101st Air Mobile Division, Fort Campbell, Kentucky, for data on current procedures, tactics, and logistic problems.

- The U.S. Army Transportation Center, Fort Eustis, Virginia, for data on doctrine, tactics, procedures, and rigging, both current and future.

- Night Vision Labs, Fort Belvoir, Virginia, for data on night operations.

During these trips, emphasis was placed on:

- Sling and netted load missions performed by current assault companies, training schools, and combat operations.

- Acquisition and Deliveries. Procedures used by ground crew, including techniques of loading, computing load weight distribution, hookup, content of pre-mission briefing, and emergency procedures (either planned or practiced).

- Weather conditions encountered or anticipated and limits (wind, darkness, etc.) now restricting operations.

- Weather conditions considered as limits.

- Special procedures and hazards, such as static electricity.

- Projections of special equipments and procedures to be used during IFR, such as night vision goggles, and FLIR.

- Tactical maneuvers and sling load missions anticipated with the next-generation helicopter.

At the above locations, the technique for collecting data was by:

- Structured interviews

- Structured questionnaires

- Observation of flights and sling load procedures

- Tape recording

Appendix B contains the complete questionnaire used and a summary of the results.

Flight Crew Task Analysis. Flight crew task analysis involves the division of duties between the pilot, copilot, and crew chief. All tasks identified for the flight crew were further broken down into the following categories:

- Visual. Any task or discrete activity that requires a member of the crew to look outside (external) or inside the aircraft (internal) for other than basic control of the aircraft, or that was directly applicable to the continuance of the mission.

- Manual. Any discrete task that requires an identifiable action with the hands or feet for other than basic control of the aircraft.

- Audio (plus Verbal). Communications and sound feedback, both external and internal, directly relating to external cargo operations, including interphone conversations between members of the crew.

Specific steps taken in the flight crew task analysis were:

- Each mission phase segment was broken down into specific crew member tasks.

- A delineation was made as to the task category, i.e., manual, visual, or audio.

- Differences in crew member tasks for each aircraft were identified.

Figure 2 is an example of the flight crew task analysis.

Ground Crew Task Analysis. Ground crew task definitions were based on interviews, observations, and Army Technical Manuals. Ground crews are divided into the signalman, hookup man, and an assistant. This is the normal crew and will vary depending on the mission and load. Ground crew tasks are readily

FLIGHT CREW TASK ANALYSIS

PHASE: 3.0 HOOKUP

PILOT TASKS				COPILOT TASKS				CREW CHIEF TASKS			
SEGMENT/TASK	MANUAL	VISUAL	AUDIO	SEGMENT/TASK	MANUAL	VISUAL	AUDIO	SEGMENT/TASK	M	V	A
3.1 MANEUVER OVERLOAD	X	X									
3.1.1 Adjust helio ht to clear load				3.1.1 Scan load for proper riggin[illegible]		X		3.1.1 Monitor PZ for obstruction clearance		X	
3.1.2 Receive "Hook-Armed" message from C.P.			X	3.1.2 Place hook switch in "Arm"	X			3.1.2 (CH47 & UH60) Assume position at hook and prepare to direct pilot.	X	X	
3.1.3 Hover towards load following ground signalman	X	X		3.1.3 Verify "Arm" light and inform pilot		X	X				
				3.1.4 Monitor engine inst. for normal leadings		X		3.1.2 (UH-1H) Assume position so hook-up can be visually monitored	X		
NOTE: At this point UH-1H and UH-60 tasks differ from CH47.				3.1.5 Place piloths external radios off at ICS and inform pilot	X		X	3.1.2 (CH47) Inform pilot when load is in sight		X	X
3.1.4 (CH47) Receive message from C.P. that external radios have tuned "off" at pilot ICS.			X	3.1.6 Continue to monitor instruments and scan PZ for obstacle clearance		X		3.1.3 (CH47 & UH60) Receive "load" under nose message and start directing aircraft to load.		X	X
3.1.5 (CH47) Call "Load Under Nose" to crew chief.			X								
3.1.6 (CH47) Follow crew chief directions to place hook over load	X	X	X					3.1.6 (CH47 & UH60) Inform pilot when hook is over load		X	X

Figure 2. Typical flight crew task analysis sheet.

identifiable. The signalman is the most important member of the ground crew. He controls the movements of the aircraft by his signals, judgement, and experience. He must be trained and experienced so that the pilot understands and has confidence in his directions. Hand signals must be accurate and timely so that the hookup can be made with minimum movement and time. The two hookup men (the assistant hookup man uses the static discharge probe to discharge the hook) are exposed to many hazards associated with hookup under the aircraft and from downwash.

Task Analysis Findings. Flight crew acquisition tasks were found to be similar for all three aircraft analyzed. The CH-47 crews normally used the onboard crew chief to direct the pilot to the load in lieu of the ground guide. The UH-60 crew chief could function in a similar method; however, at present, ground guides are being used primarily. Due to acquisition procedures and equipment, the pilot accomplishes most of the tasks, while the copilot is used primarily as a safety observer. This unequal distribution of tasks is partially caused by almost total lack of instrumentation for the acquisition process. The flight crew is required to acquire the load "in the blind," with only secondary outside directions. This results in slow, hazardous operations even in perfect visibility conditions.

Workload Studies

Workload for this study is defined as the ratio of performance time to time available. The available time is defined as the average time required and is based on a time-line analysis. In relationship to operator activity, it is the sum of operator workload and the operator's free time. If it takes 100 percent of the operator's time to accomplish the external load tasks and he has no free time, then his workload is 100 percent. If the operator has time to rest or perform nonmission tasks, then his workload would be less than 100 percent. The operator's workload is made up of several activities; for this study, visual, manipulative, and oral/auditory activities only were considered.

Workload Analysis Procedures. The time required (workload) for each of these activities was based on observed times

documented during flight and simulator tests[6,7,8]. Using the completed task analyses and time lines, pilot workloads were determined for each segment and phase of the mission.

Results of these studies confirmed previous reports that workloads were highest during hookup and lowest during transport. Pilot visual workload for all phases except transport exceeded normal acceptable continuous levels. Copilot activities during all phases were minimal.

Baseline Workloads. A baseline workload was defined for each task category. To simplify the baseline, cyclic control was selected to represent the manipulative activity. Pilot tasks were selected because they were the most prominent and critical. Sling-rigged high-density loads using a net were selected as the types of rigged load. The baseline workload would represent a typical current aircraft and mission, and would be VMC daytime, using a three-man ground crew. Figure 3 presents a graphical representation of the baseline workloads.

Poor Visibility Effects

Poor visibility during acquisition is primarily the visual restriction created by helicopter downwash. These conditions are caused by blowing dust, sand, and/or snow and can reduce the pilot's visual cues to the point that the PZ or DZ is completely obscured. An approach and acquisition under these conditions is made at high risk to the crew and aircraft.

Study and observation of downwash indicates that onset can be expected at approximately 50-foot above ground level (AGL) (or one rotor diameter). The density of the dust particles will increase in proportion to the altitude and speed of the helicopter. The closer to the ground the more dense the particles become, and the slower the aircraft moves over the ground, the more dense the particles will become.

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6. Strother, D., VISUAL AND MANUAL WORKLOAD OF THE HELICOPTER PILOT, Proceedings of the 30th Annual National Forum of the American Helicopter Society, May 1974, Washington, D. C.

7. Barnes, J. A., ANALYSIS OF PILOT's EYE MOVEMENTS DURING HELICOPTER FLIGHT, Human Engineering Laboratory, U. S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, Maryland, April 1972.

8. Frezell, T. L., Hofmann, M. A., and Oliver, R. E., AVIATOR VISUAL PERFORMANCE IN THE UH-1H, USAARL Report No. 74-7, Army Aeromedical Research Laboratory, Fort Rucker, Alabama, October 1973.

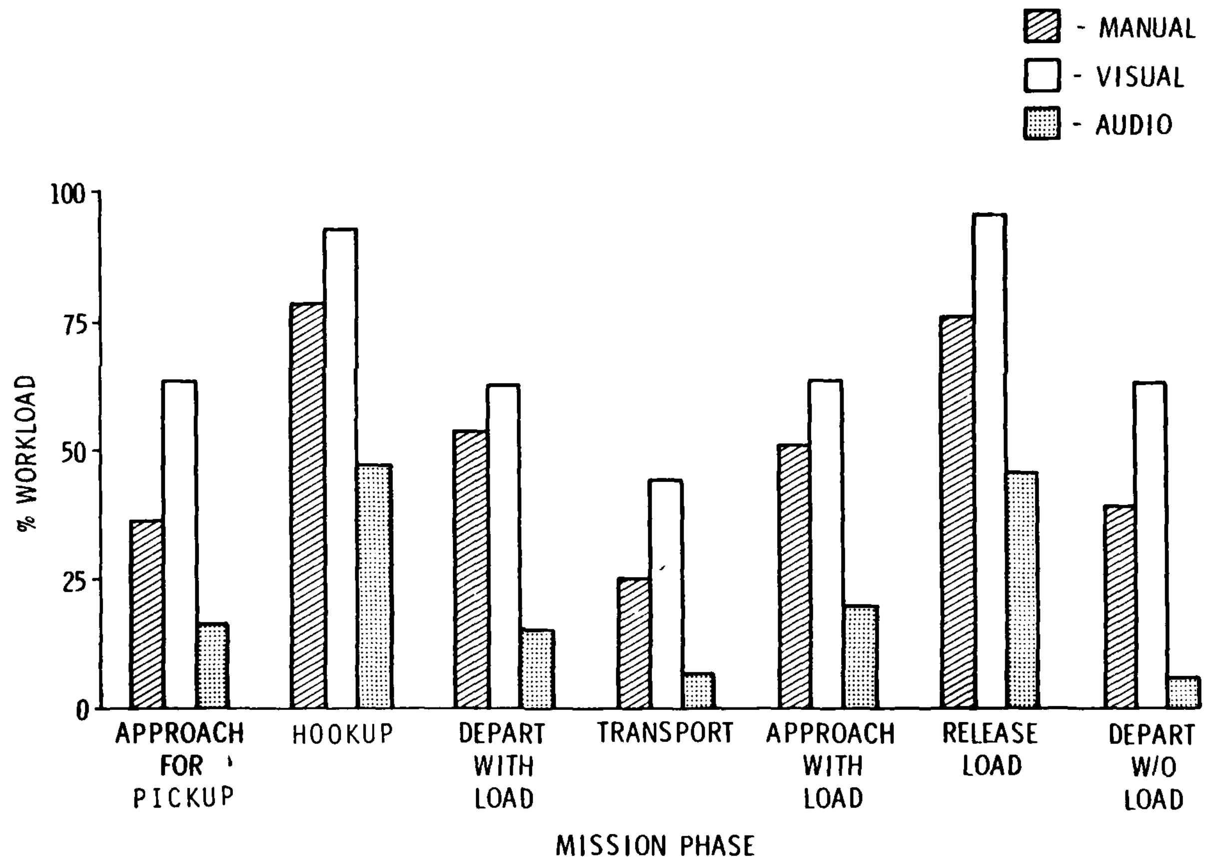

Figure 3. Baseline workload.

Pilot techniques have been developed to minimize the effect of downwash. These techniques involve flying the aircraft ahead of the particle cloud, making a shallow approach and terminating at the ground to avoid hovering; or, if a steep approach is required, termination is made out of ground effect and then a rapid descent to the ground. However, due to the requirement of prolonged hover near the ground, external load operations cannot use these techniques. At the present time, if these conditions are encountered, the mission may be aborted.

To study this problem further, an analysis was made of the flight crew information requirements and current sources during the various phases of external load mission. Three visibility conditions in the PZ/DZ were considered: VMC (clear), marginal (visibility restriction down to 10 feet), and full IMC (no outside cues visible). Figure 4 presents the results of this analysis. Primary and secondary sources are identified. If no current information source is available to the flight crew, it is noted. Several factors become immediately obvious: safe IMC hover is impossible, altitude control is difficult, and detection of movement over the ground is almost impossible.

Effects of Night on Workload. Pilot workload during night VMC operations is much greater than day IMC. PZ/DZ operation at hover, as during hookup and release, is much more difficult due to the reduced visibility and lack of depth perception. As the level of starlight and/or moonlight is reduced, the workload increases. The visual workload at night VMC will approach the day IMC workload. Figure 5 depicts the shifting of information sources as visibility is reduced. The baseline workload was reevaluated for effect of a normal starlight non-aided mission. Figure 6 summarizes the results of this evaluation.

Effects of IMC on Workload. As the visibility deteriorates due to downwash or meteorological conditions (fog, rain, etc.), increased limitations are placed on the flight crew. During hookup or release operations, the pilot loses his ability to accurately position the helicopter either horizontally or vertically. This results in increased workload. The workload increases with reduction in visibility until, due to lack of information sources, the pilot reaches an overload condition and enters a very hazardous condition. The lack of an IFR capability at hover forces the pilot to abort his mission when this condition occurs or remains in a most dangerous situation. Figure 7 is a representative workload during marginal conditions. These conditions occur during hovering for

TASK	① EXT / INT	ATTITUDE CONTROL VMC	ATTITUDE CONTROL MARG	ATTITUDE CONTROL IMC	② AIRSPEED VMC	② AIRSPEED MARG	② AIRSPEED IMC	VERTICAL SPEED VMC	VERTICAL SPEED MARG	VERTICAL SPEED IMC	ALTITUDE VMC	ALTITUDE MARG	ALTITUDE IMC	③ POSITION/COURSE VMC	③ POSITION/COURSE MARG		THRUST/POWER VMC	THRUST/POWER ④ MARG	THRUST/POWER ⑤ IMC
								DAYTIME											
APPROACH (2.0)																			
2.1	E	P	P	-	P	S	-	P	S	-	P	S	-	P	P	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	S	P	S	P	P
2.2	E	P	P	-	P	S	-	P	S	-	P	S	-	P	P	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	S	P	S	P	P
2.3	E	P	P	-	P	P	-	P	P	-	P	P	-	P	P	-	P	S	-
	I	-	S	**	S	**	**	-	-	P	-	S	**	-	S	P	S	P	P
HOOKUP (3.0)																			
3.1	E	P	P	-	P	P	-	-	-	-	P	P	-	P	P	-	P	S	-
	I	-	-	**	-	**	**	-	-	-	-	**	**	-	**	**	-	P	P
3.2	E	P	P	-	-	-	-	-	-	-	P	P	-	P	P	-	P	S	-
	I	-	-	II	-	-	-	-	-	-	-	**	**	-	-	**	-	P	P
3.3	E	P	P	-	-	-	-	P	P	-	P	S	-	P	P	-	P	S	-
	I	-	**	**	-	-	-	-	**	**	-	**	**	-	**	**	-	P	P
3.4	E	P	P	-	-	-	-	-	-	-	P	P	-	P	P	-	P	S	-
	I	-	**	**	-	-	-	-	-	-	-	**	**	-	**	**	-	P	P
DEPARTURE (4.0)																			
4.1	E	P	P	-	P	S	-	P	S	-	P	S	-	P	P	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	**	**	-	P	P
4.2	E	P	P	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	P	P*	-	P	P
4.3	E	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P*	S	P	P
TRANSPORT (5.0)																			
5.1	E	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P
5.2	E	P	S	-	P	S	-	P	S	-	P	S	-	I	S	-	P	S	-
	I	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P
5.3	E	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P	S	P	P

Figure 4. Information requirement.

TASK	(1) EXT / INT	ATTITUDE CONTROL VMC	ATTITUDE CONTROL MARG	ATTITUDE CONTROL IMC	(2) AIRSPEED/HORIZONTAL MOVEMENT VMC	AIRSPEED/HORIZONTAL MOVEMENT MARG	AIRSPEED/HORIZONTAL MOVEMENT IMC	VERTICAL SPEED VMC	VERTICAL SPEED MARG	VERTICAL SPEED IMC	ALTITUDE VMC	ALTITUDE MARG	ALTITUDE IMC	(3) POSITION/COURSE VMC	POSITION/COURSE MARG	POSITION/COURSE IMC	THRUST/POWER VMC	THRUST/POWER (4) MARG	THRUST/POWER (5) IMC
APPROACH (6.0)																			
6.1	E	P	P	-	P	S	-	P	S	-	P	S	-	P	P	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	S	P	S	P	P
6.2	E	P	P	-	P	S	-	P	S	-	P	S	-	P	P	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	S	P	P	-	S	P	S	P	P
6.3	E	P	P	-	P	S	-	P	S	-	P	P	-	P	P	-	P	S	-
	I	-	S	P	**	**	**	S	P	P	-	**	**	-	S	P	S	P	P
RELEASE LOAD (7.0)																			
7.1	E	P	P	-	P	P	-	-	-	-	P	P	-	P	P	-	P	P	-
	I	-	**	**	-	**	P**	-	-	-	-	S**	P**	-	**	**	S	S	P
7.2	E	P	P	-	-	-	-	P	P	-	P	P	-	P	P	-	P	P	-
	I	-	**	**	-	-	-	-	**	**	-	**	**	-	**	**	-	S	P
7.3	E	P	P	-	-	-	-	-	-	-	-	-	-	P	P	-	P	P	-
	I	-	**	**	-	-	-	-	-	-	-	-	-	-	**	**	-	S	P
7.4	E	P	P	-	-	-	-	-	-	-	P	P	-	P	P	-	P	P	-
	I	-	**	**	-	-	-	-	-	-	-	**	**	-	**	**	-	S	P
DEPARTURE (8.0)																			
8.1	E	P	P	-	P	P	-	P	P	-	P	S	-	P	[illegible]	-	P	S	-
	I	-	S	P	-	S	P	-	S	P	-	P	P	-	S	P	-	P	P
8.2	E	P	P	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	-	S	P	S	P	P	S	P	P	-	P	P	-	P	P	-	P	P
8.3	E	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-	P	S	-
	I	-	P	P	S	P	P	S	P	P	-	P	P	-	P	P	-	P	P

NOTES:

(1) E - EXTERNAL INFO SOURCE; I - INTERNAL INFO SOURCE

(2) AIRSPEED IN FLIGHT - HORIZONTAL MOVEMENT SPEED WHILE HOVERING

(3) IN FLIGHT - NORMAL NAV INFO; IN PZ/DZ - POSITION RELATIVE TO LOAD

(4) MARG - MARGINAL VISIBILITY IN FLIGHT CONSISTS OF PARTIAL OBSCURITY; IN PZ/DZ, PARTIAL OBSCURITY IS MORE THAN 10 FT

(5) IMC - IN FLIGHT NORMAL IFR LESS THAN 100 FT CEILING; IN PZ/DZ, VIS LESS THAN 10 FT

** NO CURRENT INFORMATION SOURCE AVAILABLE

Figure 4. (continued)

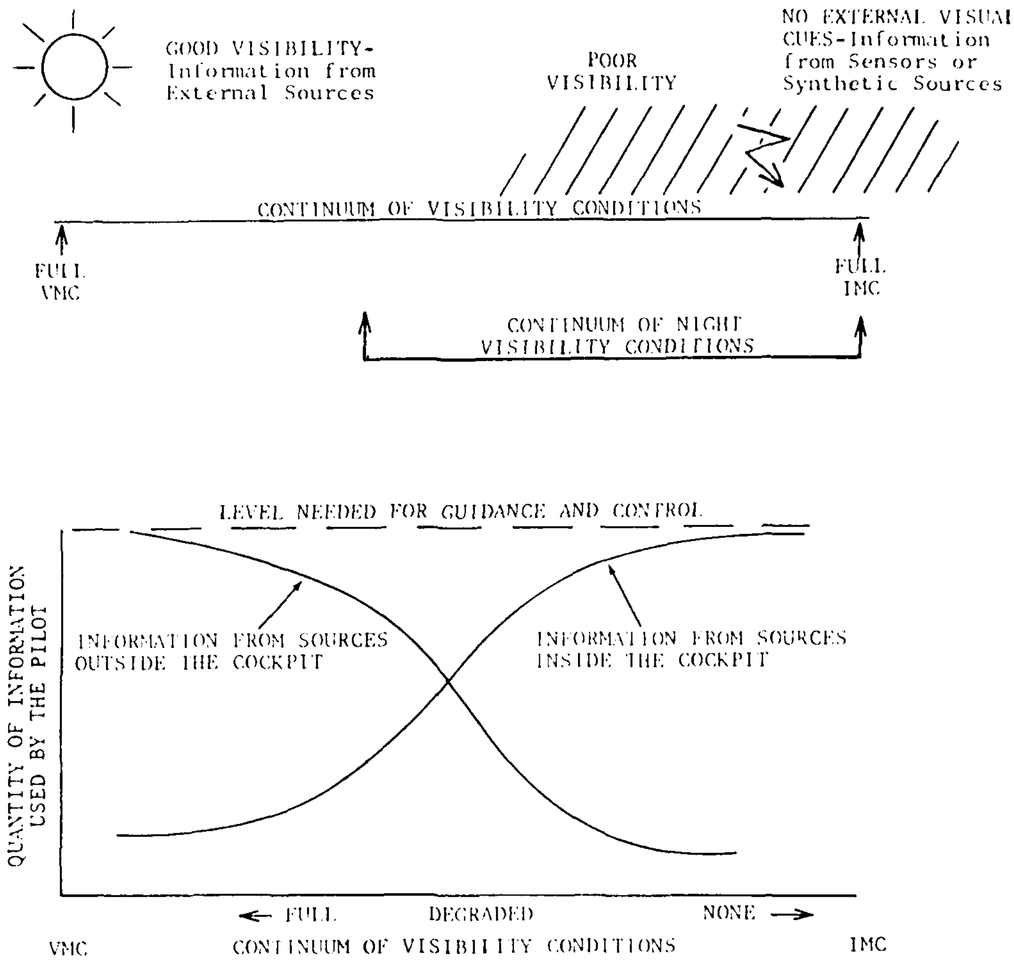

Figure 5. Sources of pilot visual information.

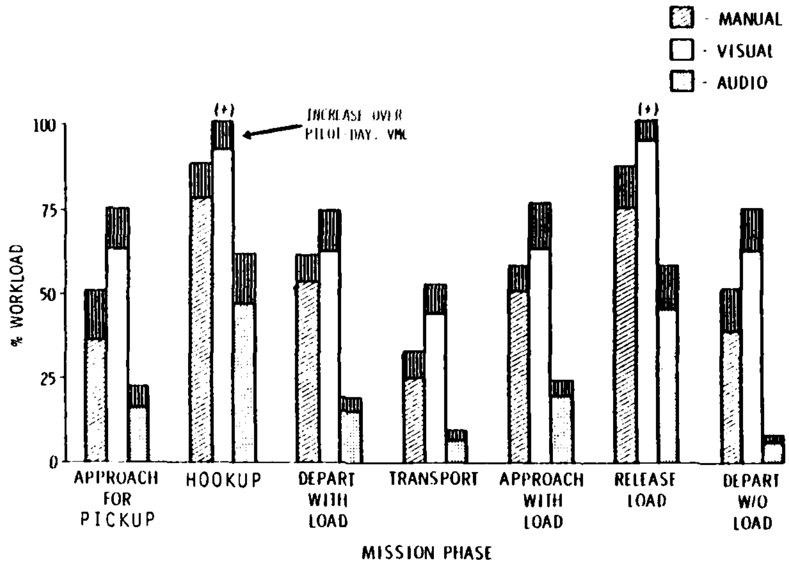

Figure 6. Workload - night.

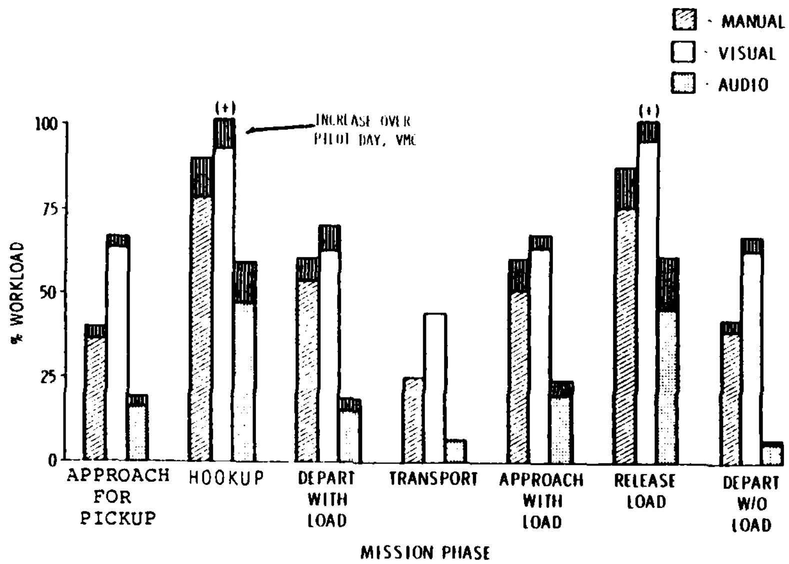

Figure 7. Workload - marginal visibility.

hookup or release when visibility is reduced due to blowing dust, sand, or snow to as low as 10 feet. It should be noted that this figure is for day-marginal. Night-marginal conditions are considered similar to IMC and should not be attempted due to lack of instrumentation.

HAZARD ANALYSIS

Analysis Procedure

As part of the Phase I study, the hazards encountered in the external load mission were analyzed. This analysis identified hazardous activities, classified them by category, and highlighted those areas that required attention. The hazard analysis procedures and format from previous system safety programs were utilized. Slight modification to the format was made to adapt it to the acquisition tasks. Hazard level categories as defined by MIL-STD-882A were used to classify identified hazards. This systematic approach provided identification of potential hazards in current operations as well as guidance in selecting alternate technical and procedural candidates for improved acquisition.

Hazard Categories

A hazard is defined as an existing or potential condition that can result in a mishap. Hazard severity categories are defined to provide a qualitative measure of the worse potential consequences resulting from personnel error, environmental conditions, design inadequacies, procedural deficiencies, or system, subsystem or component failure or malfunction as follows:

- Category I - Catastrophic. May cause death or system loss.

- Category II - Critical. May cause severe injury, severe occupational illness, or major system damage.

- Category III - Marginal. May cause minor injury, minor occupational illness, or minor system damage.

- Category IV - Negligible. Will not result in injury, occupational illness, or system damage.

Analysis Results

Each phase of the mission was analyzed for potential hazards. The resulting hazards were then ranked in order of their

severity. Table 2 presents a summary of this severity ranking by mission phase. Several factors become evident as a result of the hazard analysis. In all phases, margin of lift was a prime factor in severity classification. Other major factors were obscured pilot vision, downwash, and load stability. The following is a listing, by mission phase, of the major factors associated with the identified hazards.

<u>Approach for Pickup Phase</u>

- Obstacle strike
- Pilot disorientation

    Night operations
    Obscured vision
    Weather-related factors (snow, fog, rain)

<u>Hookup Phase</u>

- Ground Personnel Injury

    Shock from static electricity
    Falling off load
    Struck by helicopter

- Excessive Maneuver and Time Exposed to Hostile Fire

    Night operation
    Obscured vision - rotor wash
      Ground debris
      Weather related factors (snow, fog, rain)

- Margin of Lift Capability

<u>Departure with Load Phase</u>

- Marginal lifting capability
- Load stability
- Obstacle strike
- Inadvertent load release

TABLE 2. HAZARD ANALYSIS SUMMARY

MISSION PHASE	HAZARD SEVERITY CATEGORY I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
2.0 APPROACH FOR PICKUP				
2.1 INITIATE DESCENT	1			
2.2 DESCENT	2			
2.3 TERMINATE DESCENT	1	1		
3.0 HOOKUP				
3.1 MANEUVER OVERLOAD	2			
3.2 ATTACH SLING TO HOOK	1	4	1	
3.3 RAISE LOAD OFF GROUND	2	1		
3.4 PREPARE FOR TAKEOFF	1			
4.0 DEPARTURE WITH LOAD				
4.1 INITIATE CLIMB		3	1	
4.2 CLIMB OUT	2	1		
4.3 INITIATE LEVEL-OFF		1	1	
5.0 TRANSPORT LOAD				
5.1 ESTABLISH & MAINTAIN LEVEL FLIGHT			1	
5.2 CRUISE TO DROP ZONE (DZ)			1	
5.3 IDENTIFY DZ AND VERIFY CONDITION				1
6.0 APPROACH WITH LOAD				
6.1 INITIATE DESCENT			2	
6.2 DESCENT		2	2	
6.3 TERMINATE DESCENT		2	1	
7.0 RELEASE LOAD				
7.1 MANEUVER TO RELEASE POINT	2	1	1	
7.2 LOWER LOAD TO GROUND			3	
7.3 RELEASE LOAD FROM HOOK	1			1
7.4 PREPARE FOR TAKEOFF			1	

Transport Load Phase

- Load stability
- Pilot disorientation

    Night operation
    Obscured vision
    Weather-related factors (snow, fog, rain)

Approach with Load Phase

- Marginal lifting capability
- Load stability
- Pilot disorientation

    Night operation
    Obscured vision
    Weather related factors (snow, fog, rain)

- Obstacle strike

Release Load

- Marginal lifting capability
- Excessive maneuver and time exposed to hostile fire
- Pilot disorientation

    Night operation
    Obscured vision - rotor wash
    Ground debris
    Weather-related factors (snow, fog, rain)

- Inadvertent load release
- Load stability
- Obstacle strike

PHASE II

The first major task of Phase II consisted of extensive technology investigations, surveys, and searches to identify potential alternate acquisition system candidates. The following major sources were used for identifying candidates:

- Published reports
- Military users (questionnaire)
- Commercial users
- Manufacturers

In addition, a trip was made to a commercial helicopter operator, Evergreen Helicopters, McMinnville, Oregon, to obtain additional data on commercial solutions to external load acquisition. The detailed results of this trip are included in Appendix B.

After potential candidates were identified, the second major task was to evaluate each concept for improvement over the baselines established in Phase I. The candidates were then ranked in accordance with this improvement.

ALTERNATE CANDIDATE SELECTION

Selection Criteria

Candidate systems/concepts were selected based on the requirement that they must have potential for improvement in the acquisition process of external load operation. The potential candidates must be applicable to utility and medium helicopters. The improvement must be for pre-rigged loads using either slings or nets. Concepts that were primarily for loads that did not use slings or nets, such as HEGS[9], were not considered for evaluation.

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9. Porterfield, J. D., DESIGN ASSESSMENT OF ADVANCED TECHNOLOGY LIGHTWEIGHT, LOW-COST MISSION CONFIGURED GONDOLA MODULES, Kaman Aerospace Corp., USARTL Report 79-16, Applied Technology Laboratory, U. S. Army Research and Technology Laboratories, Fort Eustis, Virginia, July 1979, AD A073554.

The following problem areas, as identified and analyzed in Phase I, were used as selection criteria for alternate candidates:

- Reduce crew workload
- Eliminate crew tasks
- Improve safety (reduce hazards)
- Improve mission effectiveness

    Improve night operations

    Improve IMC operations

General Acquisition Improvements

Several general improvements were determined to be required for external load acquisition. All current helicopter handling qualities require improvement for IMC hover and operations in low visibility conditions. This handling improvement could be in the form of attitude and/or altitude hold. Most studies and reports of IMC operations, including this study's questionnaires (Appendix B), indicated that improvement was required.

Because height is extremely important to the acquisition process, precise altitude is required, especially for improved operations in low-visibility, night, and IMC conditions. During approach and hookup, height above the load is vital. At present, the flight crew must rely on visual judgement for clearance, which is only approximate when visibility is good, and rapidly deteriorates as the visibility decreases. The importance of height determination during transport of the external load was thoroughly analyzed in References 10 and 11.

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10. Alansky, I. B., Davis, J. M., and Garnett, T., LIMITATIONS OF THE CH-47 HELICOPTER IN PERFORMING TERRAIN FLYING WITH EXTERNAL LOADS, Boeing Vertol Company; USAAMRDL Report TR 77-21, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, August 1977, AD A048580.

11. Alansky, I. B., Davis, J. M., and Garnett, T., LIMITATIONS OF THE UTTAS HELICOPTER IN PERFORMING TERRAIN FLYING WITH EXTERNAL LOADS, Boeing Vertol Company; USAAMRDL Report TR 77-22, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, September 1977, AD A047568.

One of the most difficult tasks that the flight and ground crews have is determination of cargo weight. Fixed-wing transports use "weight-on-gear" type indications to assist the crew. During helicopter external load operations, the flight crew seldom has an opportunity to weigh a load before acquisition. The first chance the flight crew has is during the "lift-off-ground" phase. The pilot then has to rely on engine performance indications to ascertain if the load weight is acceptable. In most cases, this is not adequate for climb and transport. A load sensor is vital for improved external load operations. All commercial operators require load sensors and cockpit indicators. The hazard analysis indicated that the margin of lift capability was a major factor in the severity classification.

The current trend for night vision in the U. S. Army is the use of night vision goggles (NVG). A system for acquisition that would allow the crew to use the goggles would obviously be the most straightforward approach to improvement for night operations. Several of the improvement concepts discussed in this report could take advantage of the aviator night vision goggles.

Alternate Candidates

Long Line. A lanyard of cable 5 to 20 feet long with a clevis on one end and an electrical release hook on the other is conceived (Figure 8). The concept is identical with the system used by the Marines and commercial operators for external load operations. The longer cable would allow greater distance between the aircraft and load during acquisition, thus reducing downwash and allowing greater directional error for hookup and safety for the ground crew. This concept could be used with all existing aircraft and slings.

Nose Beam Mechanical Acquisition. A rod/tube extends out into the pilot visual area from beneath the aircraft (Figure 9). Affixed to this rod is a carriage device that acquires the sling apex fitting/donut by the pilot/ copilot maneuvering the device to the apex fitting. After the apex is acquired, it is transported rearward along a track on the bottom of the rod to the main hook. There the apex is attached to the hook, and the carriage device is released automatically with the main hook. An indicator in the cockpit provides apex position on the track and a locked indication of apex on the main hook. This concept will allow acquisition without ground crew assistance. Using night vision goggles, load acquisition may be acquired during blackout conditions. Optional features would

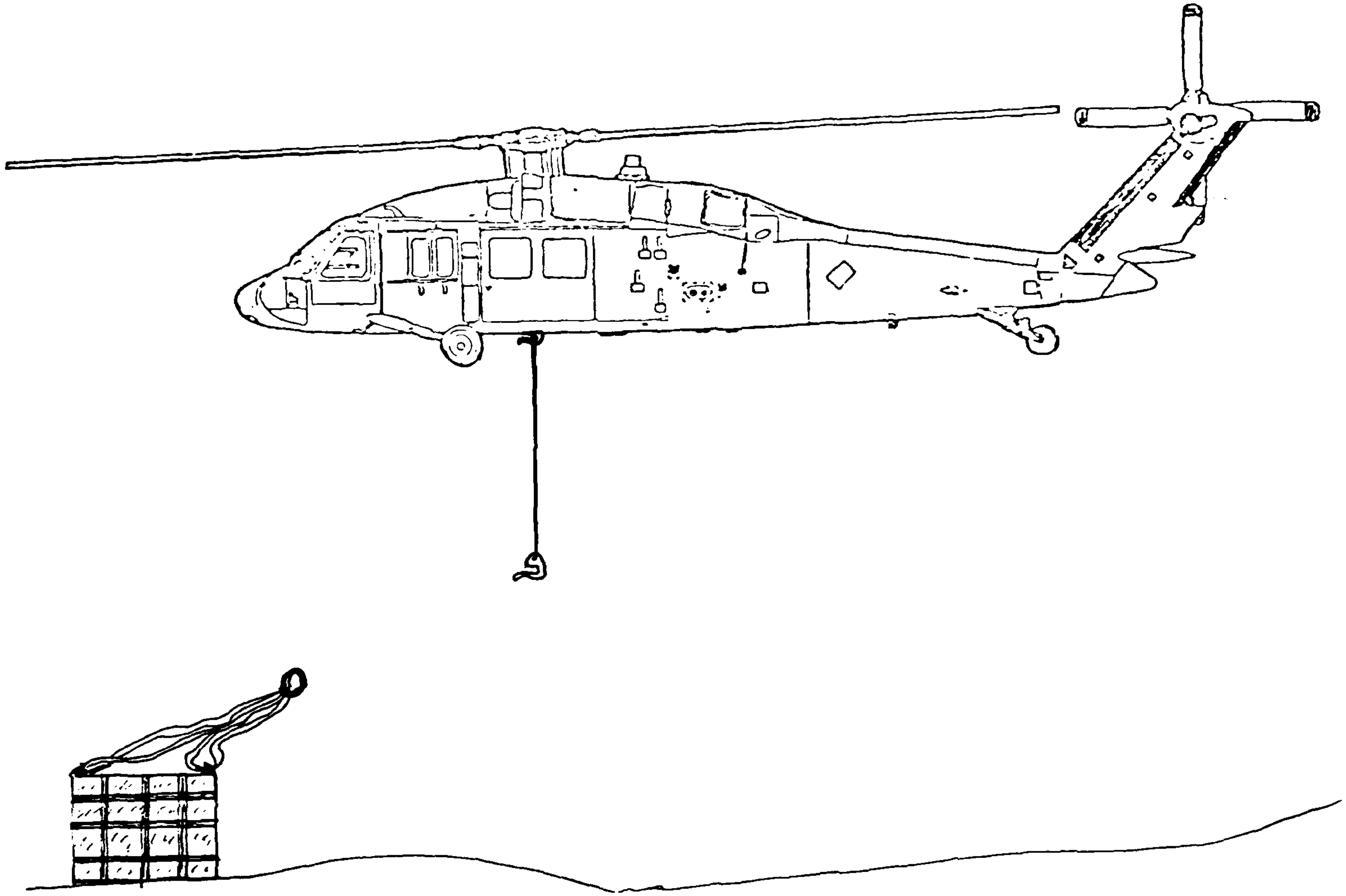

Figure 8. Lone line.

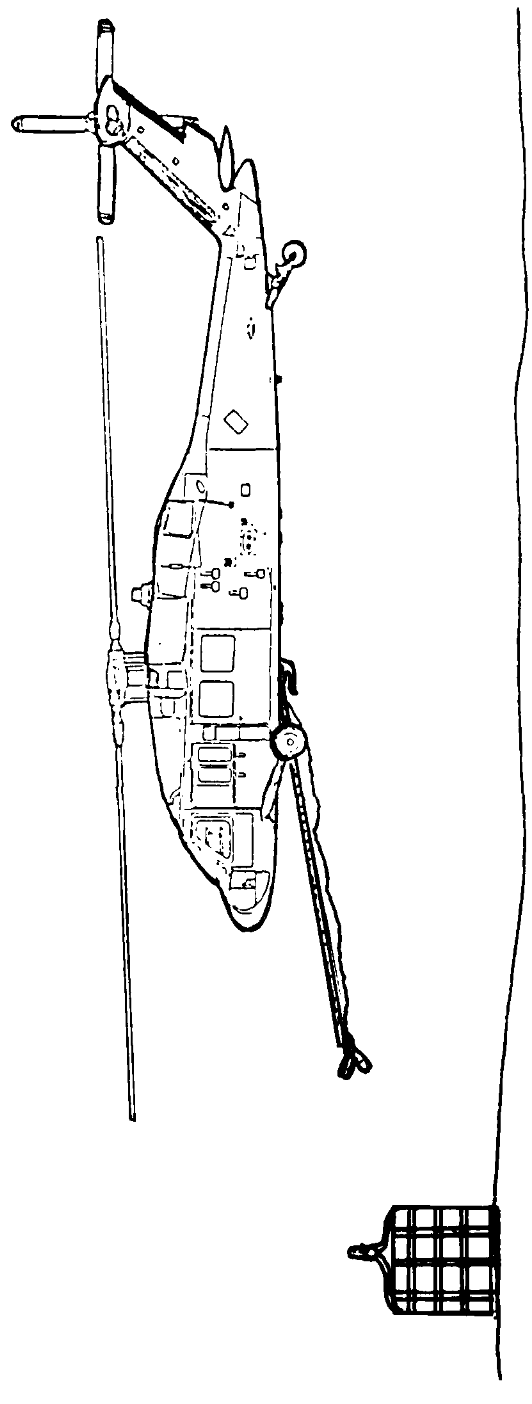

Figure 9. Nose beam mechanical acquisition

be position-and-load sensors incorporated in the carriage device to provide in-flight stabilization and load information. No known development or test programs have been conducted on this concept.

Secondary Cable Hookup. In this concept, a device or secondary cable is lowered to the load that acquires the apex fitting of the sling (Figure 10). The cable is then retracted to engage the apex on the cargo hook. The device on the end of the cable would have the capability to automatically acquire the apex fitting. This system would have the capability to be operated by either the pilot/copilot from the cockpit, the crew chief, or attachment by the ground crew. This concept could be readily adaptable to utility or medium aircraft with single or multiple hooks. Optional features could include position, load height, and lock indications. A similar concept using a pole [shepard's hook] is in use on the CH-47 models.

Extendable Arm Acquisition. An extendable arm, similar to an In-flight Refueling Probe that has a telescoping capability, would be used (Figure 11). One end of the probe would be attached to the airframe in place of the hook. The other end would terminate with a conventional hook. The airframe end would be a turret-type of termination controllable from the copilot's console. The arm would swing forward and down such that it would be visible by the flight crew. Apex acquisition could be by the ground crew or automatically by the flight crew. The copilot would be provided with a "joy-stick" to control the probe within limits to acquire the apex fitting. Once the load is acquired, the pilot would center the aircraft over the load and then proceed in a normal manner. This concept could inherently provide in-flight stabilization similar to the single active arm system.[11] Use of NVG would allow acquisition during night blackout conditions. No known development or test program has been conducted on this concept.

Hoist System. Either one or two hoists (CH-47D) would be installed in place for the existing hook. This concept would incorporate the benefits of the line with the secondary cable concepts. New technology in composites, such as Kevlar, permits a very strong hoist with light weight to be used. As visualized for the CH-47, two hoists with approximately 50 feet of Kevlar cable would be located in the same locations as the fore and aft hooks on the CH-47D (Figure 12). The configuration of the hoists would be such that they would fit between the floor and be clear of the ground with the struts compressed. The hoists would be similar to the HLH dual drum but sized for the CH-47D. Hoist control would be similar to HLH control with the copilot (left seat) acting as load controlling crewman. This concept is primarily conceived for the

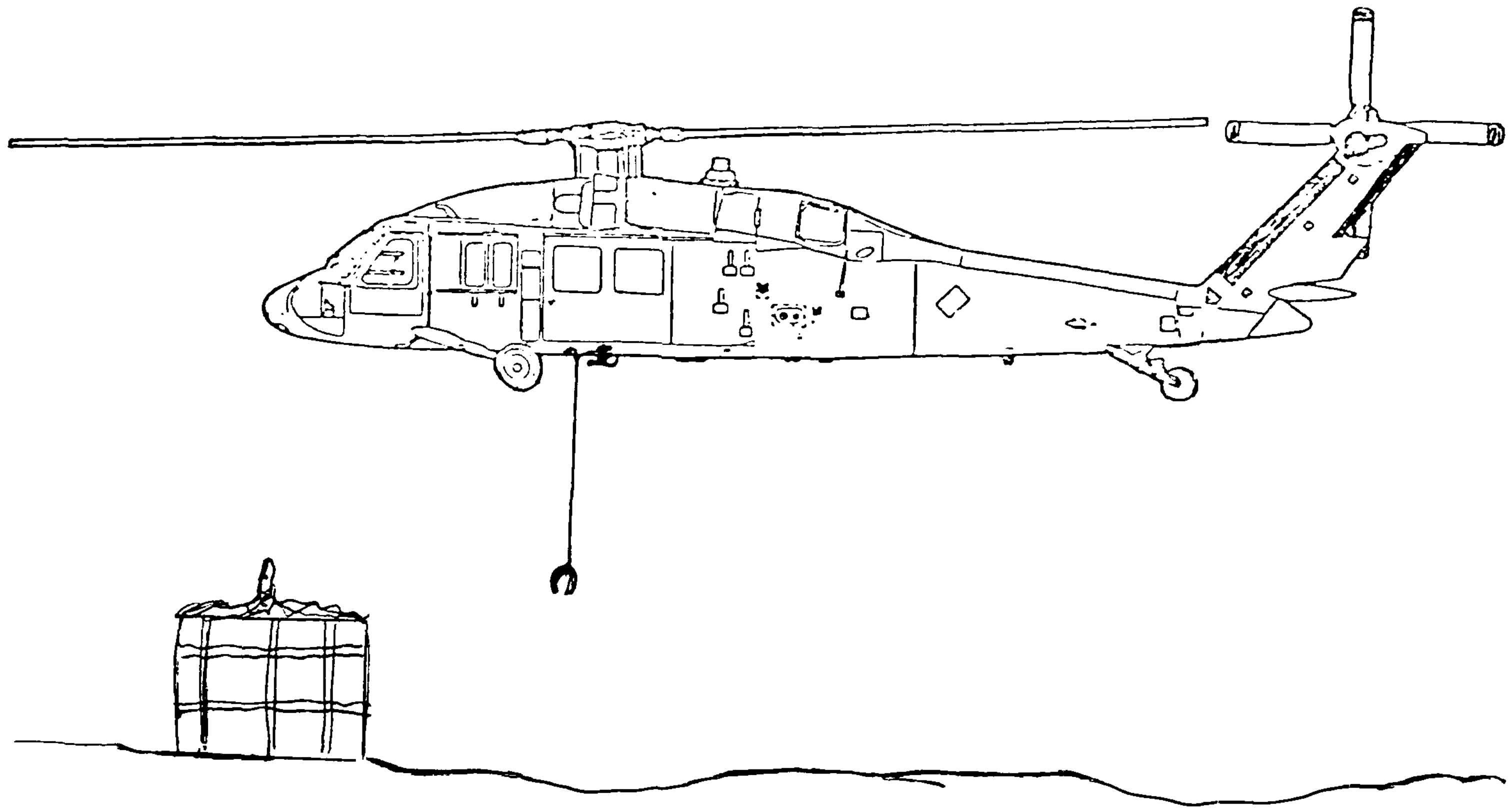

Figure 10. Secondary cable hookup.

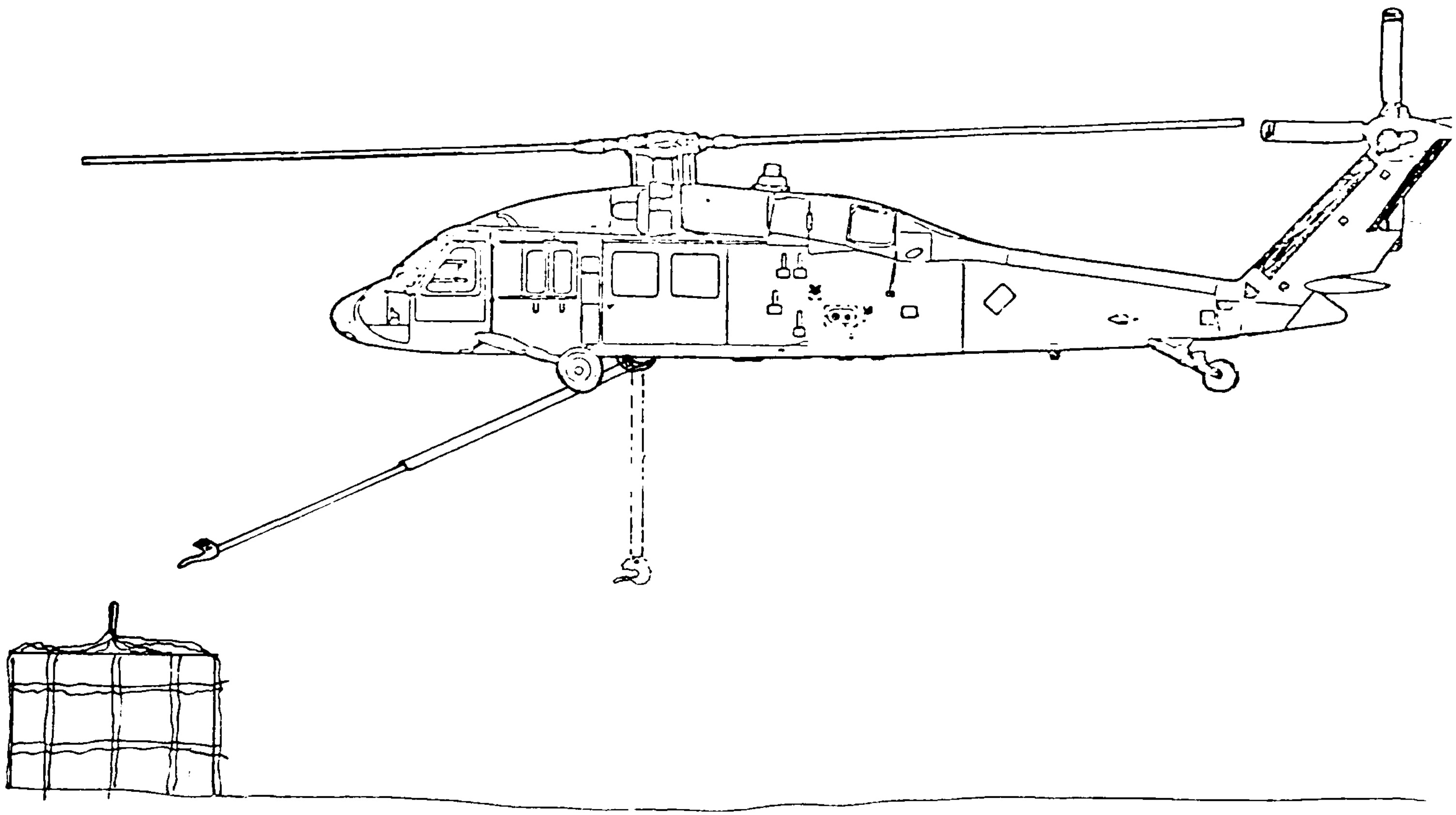

Figure 11. Extendable arm acquisition.

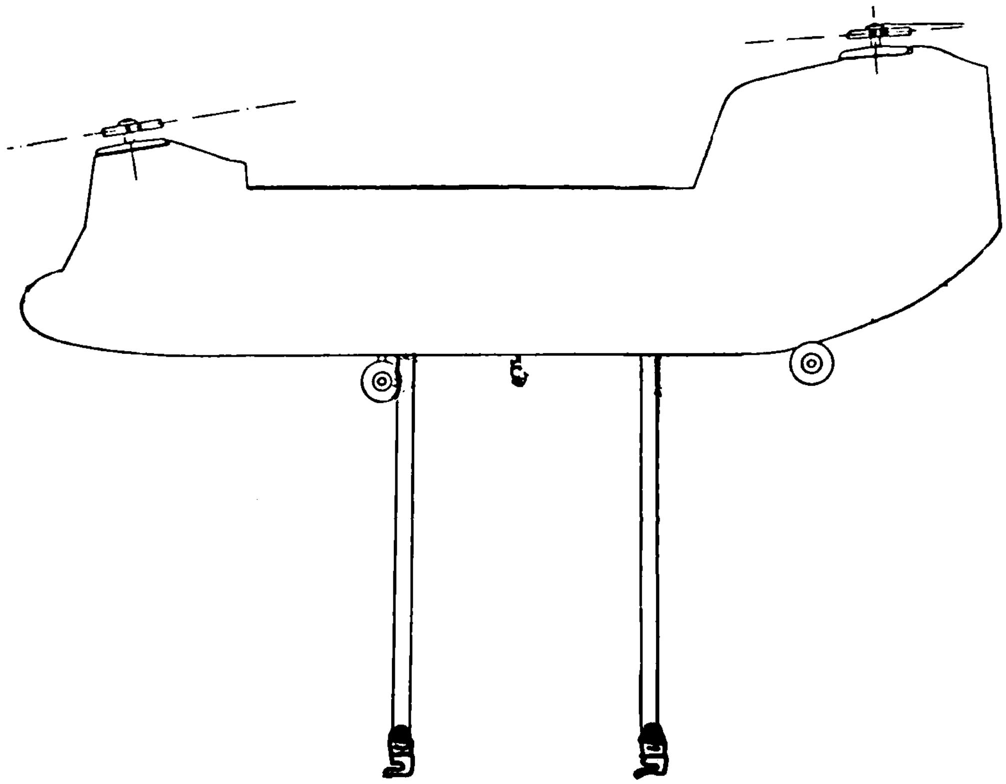

Figure 12. Hoist system

CH-47D to utilize the full potential of the increased payload and at the same time make comparable improvements in acquisition and transport. A single hoist of similar design could be installed in the UH-60. The dual hoist system has been tested as part of the HLH component development program.

Active Arm External Load Stabilization System. This concept was developed primarily to improve load stabilization during transport. However, the concept has potential for improvement in acquisition because of the extended arms. The concept as visualized for the CH-47[10] utilizes powered arms mounted below the helicopter that automatically move in response to load pendulum motion. The system would be installed in place of the fore and aft tandem cargo hooks (Figure 13). The arms are powered by servo-controlled hydraulic cylinders in the longitudinal and lateral axes, using the aircraft's utility hydraulic system. All AAELSS[10,11] control functions are from the cockpit by either pilot. While this system is designed primarily for in-flight stabilization, it also reduces pilot workload during hookup and release. A test program has been conducted on a prototype system.

A single active arm system visualized for the UH-60[11] (Figure 14) consists of a removable supporting frame bolted to the aircraft floor, from which a telescoping arm is suspended on a universal joint. Lateral and longitudinal arm motion is produced by hydraulic actuators connected between the arm and mounting frame at floor level. The lower arm installation utilizes a T-bar configuration with cargo hooks on either end to constrain yaw motion. When not in use, the lower T-section is held against the aircraft bottom surface, but is deployed into the locked position after load pickup. The system concept is not confined to any particular cargo configuration since it could readily carry artillery, CONEX containers, or possibly multiple loads such as A-22 ammunition bags. The single-arm AAELSS would perform essentially the same functions as the dual-arm CH-47 device in cutting download sway motion and reducing pilot workload appreciably. The single arm concept has not been tested.

Tandem Hook Beam. The tandem hook beam[11] converts the single-point standard aircraft cargo hook installation for dual-hook operation (Figure 15). The removable tandem hook beam would be easily installed. Electrical and mechanical hook release systems would be provided through umbilical cables. Normal load release from the aircraft would be electrical with backup mechanical operation. The tandem hook allows the pilot to deposit a load accurately and quickly in addition to maintaining in-flight stability. No development or tests have been conducted for this concept.

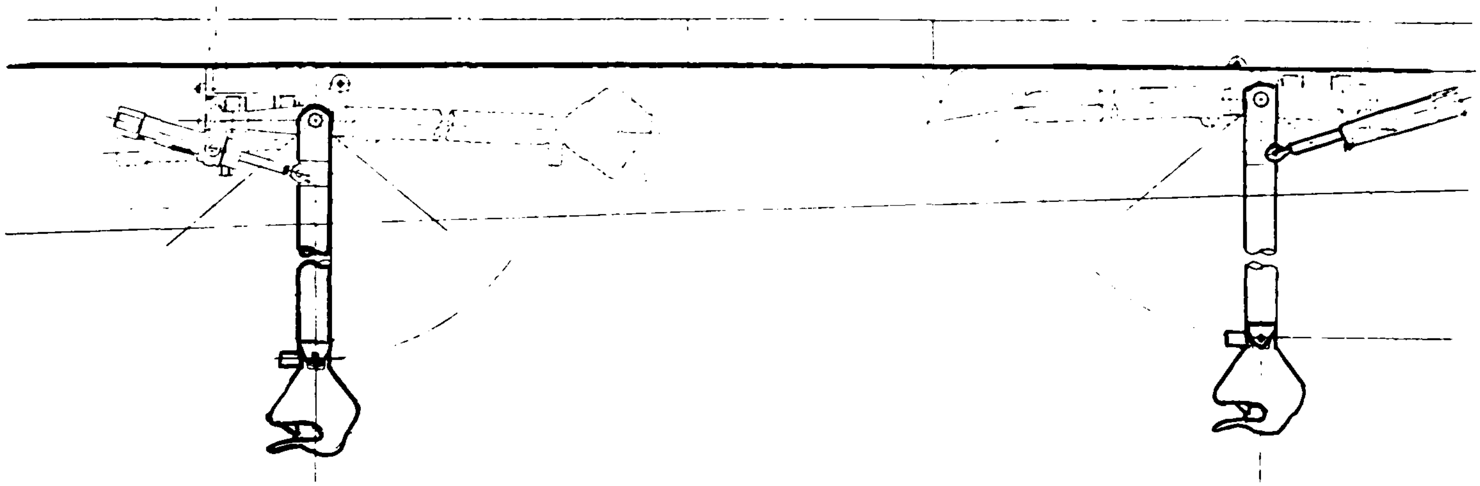

Figure 13. Dual active arm stabilization system.

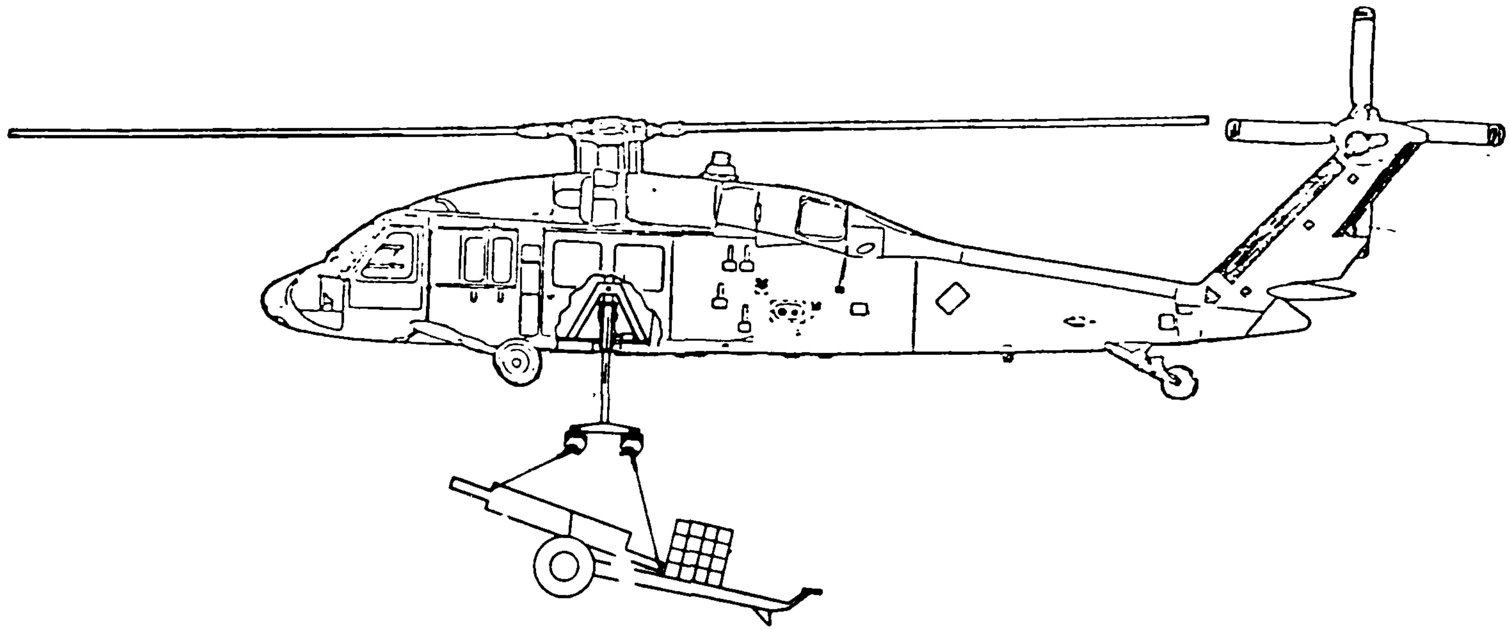

Figure 14. Single active arm system.

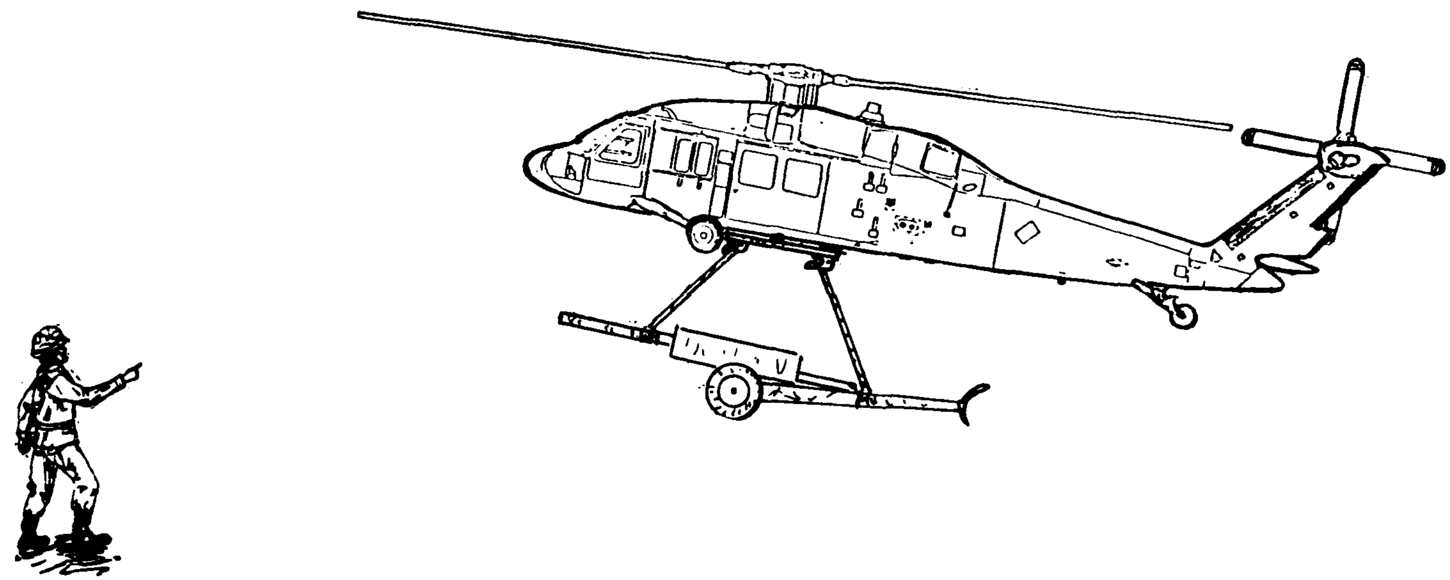

Figure 15. Tandem hook beam.

Magnetic Hookup. This concept employs magnetism to acquire the apex fitting (lifting eye). Several variations have been studied previously[12]. One concept has a lifting rod (nonmagnetic) that has special engagement and homing provisions. Just above the hook is an electromagnet that is controlled by the flight crew. The hook is of special design for ease of engagement. Other variations have multilegged lifting devices with lifting studs that replace the customary sling.

A typical concept has a self-guiding, terminal homing receptacle with a funnel-shaped opening. This funnel device is guided by an electromagnet placed at the funnel opening. Figure 16 is a sketch of this concept. No testing of this concept has been accomplished.

Indirect Aided Viewing. This concept would utilize a video-type sensor such as a TV system. Two approaches to this concept have been previously designed and tested. One approach used two airborne cameras mounted such that the pilot had a downward-looking view of the load[13]. The cockpit display was an 8-inch TV monitor installed on the left instrument panel. The two cameras displayed simultaneously through split-screen techniques.

The second closed circuit TV system approach, Visual Augmentation System (VAS), utilized a modified Cobra Night Fire Control System (CNFCS) television camera and illuminator.[14] The cockpit display used a 10-inch TV monitor with a real world presentation and super-imposed symbology for load controlling (Figure 17).

This concept would use current research and development in PNVS, FLIR, and other night vision technology. Using

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12. Liu, D. T., AUTOMATIC EXTERNAL LOAD ACQUISITION BY HELICOPTER, System Innovation & Development Corp; USAAMRDL Report 74-86, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, November 1974, AD A005051.

13. DiCarlo, D. J., Kelley, H. L., and Spivey, D. L., HELICOPTER FLIGHT INVESTIGATION TO DETERMINE THE EFFECTS OF A CLOSED-CIRCUIT TV ON PERFORMANCE OF A PRECISION SLING-LOAD HANDLING TASK, Proceedings of the 30th Annual National Forum of the American Helicopter Society, May 1974.

14. Simpson, L. F., VISUAL AUGMENTATION SYSTEM (VAS) LABORATORY DEMONSTRATION AND TEST RESULTS, Boeing Vertol Company, USAAMRDL Report 74-68, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1974, AD A003323.

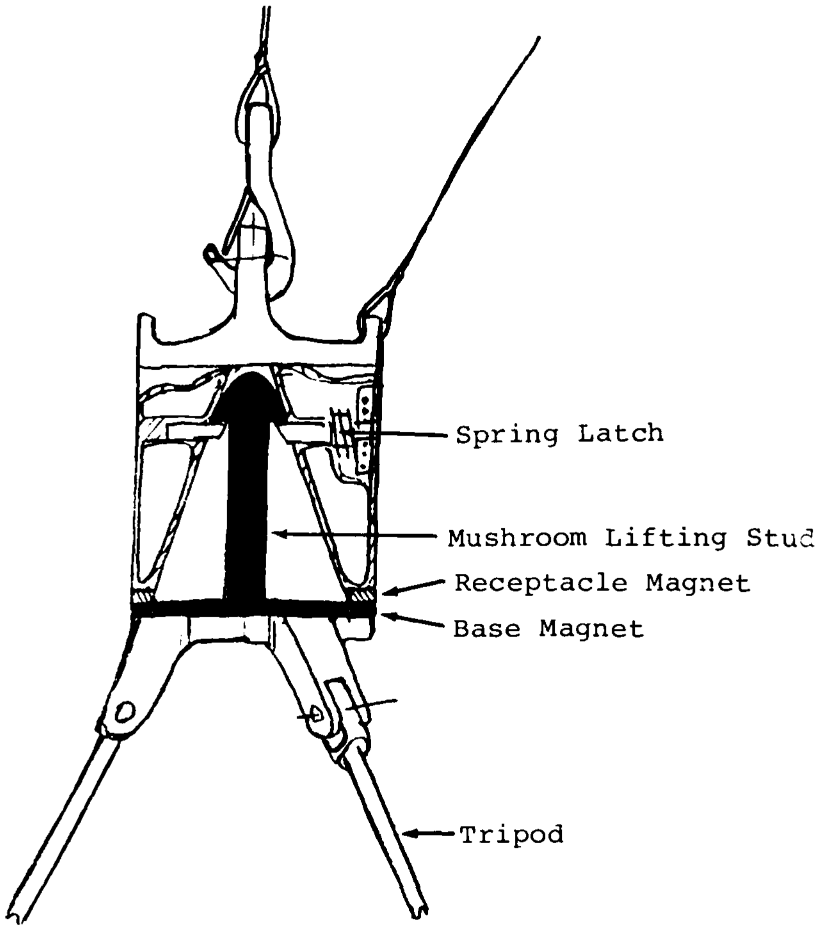

Figure 16. Magnetic hookup.

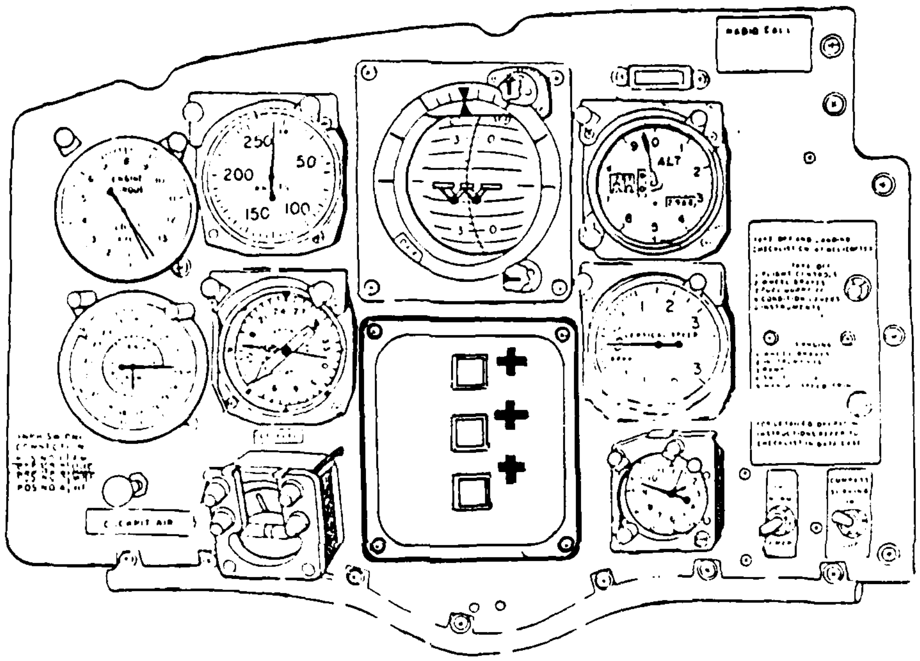

Figure 17. Cockpit video display.

a PNVS adapted from the advanced attack helicopter could provide a video view of the hook and load. Included would be ranging to provide height and range from load at night and in low visibility. Provisions would be included for normal daylight viewing also. The PNVS could be packaged in a removable turret that attaches to the underside of the fuselage. The cockpit could have a CRT display and a simple control panel on the copilot side.

Cockpit Indication and Imaging. This concept would incorporate a sensor display system that indicates relative position of helicopter to load. The displayed information would be such that the pilot could maneuver IMC to a point directly over the load without reference to external cues or directions required from other crew members. Included as an essential part of this concept is a position sensor that provides signals for relative position. The sensor would provide ranging type information as well as angular displacement. Also, velocity/closure rates would be available.

This concept uses sensors that would enable a pilot or copilot to identify a specific load, maneuver over the load, hold in position over the load, center and lift the load, and depart PZ without outside reference. The concept would reduce pilot IMC workload and make blackout and all-weather operations feasible. Properly designed, the system could also be used for obstacle avoidance and other nonexternal load operations.

Several studies have been conducted of cockpit imaging for external load acquisition.[15,16] A multicolored cathode ray tube display provided position in a geographical sense, velocity vector, attitude, altitude, collective command, collective position, and aircraft heading. The most unique feature of the display was a moving velocity vector that provided a rapid assessment of projected position, and a rapid determination of the exact azimuth direction cyclic should be moved to correct for errors. The velocity vector was obtained by summing the aircraft ground velocity with proportional aircraft attitude (Figure 18).

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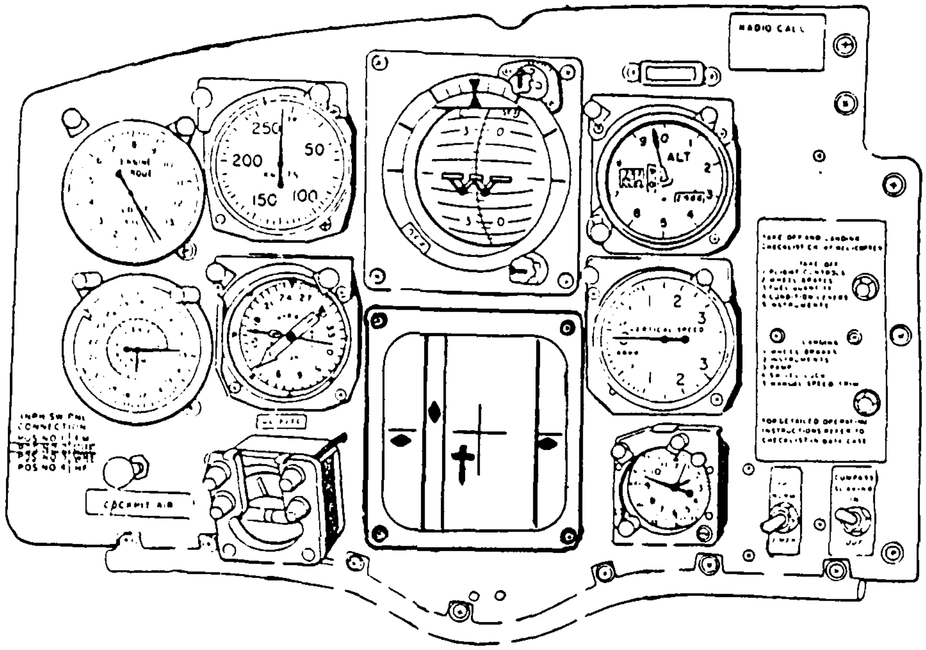

Figure 18. Cockpit imaging.

CONCEPT EVALUATION

The second major task of Phase II was to evaluate candidate concepts and rank them according to improvement over the baseline. The method of evaluation addressed the improvement as it applied to utility and medium helicopters during acquisition of sling and/or netted loads. The evaluation was based on the Phase I results, baselines, and hazard analyses for ranking, and encompassed the following parameters:

- Flight and ground crew tasks
- Flight crew workload
- Acquisition under poor visibility conditions
- Hazard categories
- Mission effectiveness

Evaluation Method

A methodology for evaluation and ranking of proposed concepts has been adapted from a method described in a previous study.[12] This evaluation method is based on assigning point counts or ratings to various criteria. A comparison of the total counts then indicates the relative ranking of each concept.

The methodology for the system assessment is as follows: Each system consideration is allocated a number of points to a maximum total. For a particular candidate, the total grade point count could be used directly to compare the relative merits of various system design concepts. This grading system, when executed without bias, should indicate not only the relative merits of a particular design but also the degree of approach to the ideal design that would have maximum point count of 1000.

The system considerations used in this concept assessment are broad enough to fit many systems; however, when interpreted in the light of the particular problem, the factors serve to establish the quality profile of each concept under consideration. To reduce the ambiguity in the concept assessment, each factor is further identified in terms of appropriate details called areas of concern. These areas will be affected, in turn, by general functional demands. Areas of concern

are allocated shares of points commensurate with their relative importance. The concept "worthiness" is reduced to the following factors of merit:

- Mission effectiveness
- Operational safety
- Ease of operation
- System performance
- Simplicity of design
- System adaptability

Areas of concern for external load acquisition have been grouped into:

- Interface related - Includes the interface between the aircraft and the load, the suspension system such as the hook and release mechanism.
- Ground crew related - Includes the rigging, the ground personnel, and their associated activities.
- Flight crew related - Includes the pilot, copilot, and crew chief and their activities.
- Helicopter related - Includes the aircraft and airborne equipment not part of the interface.

The areas of concern and the factors of merit are formed into a concept evaluation matrix. Maximum score values for the factors of merit were assigned and allocated to each box of the matrix. Certain assumptions have been made concerning the relative importance of the various areas of consideration by assigning graduated maximum point scores for each system consideration and assessment items as shown in parenthesis on the matrix chart, Figure 19. Note that most emphasis has been placed on the merit factors of "Mission Effectiveness" and "Safety," and concerns areas of "Ground Crew" and "Flight Crew."

Evaluation Discussion

As stated previously, the evaluation matrix not only indicates the relative ranking of each concept but also provides a degree of approach to the ideal system. The following paragraphs discuss ideal system ratings as applied to the study mission.

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	(50)			(50)	100
System Performance	(50)			(50)	100
Ease of Operation		(100)	(100)		200
System Adaptability	(50)			(50)	100
Operational Safety		(100)	(100)	(50)	250
Mission Effectiveness	(50)	(50)	(100)	(50)	250
TOTAL COUNT	(200)	(250)	(300)	(250)	1000

Figure 19. Evaluation matrix.

Simplicity of Design. The ideal system would contain a minimum of parts. A minimum of weight, if any, would be added to either the interface or the aircraft. Design development time and cost would be minimum. A merit rating of 100 points has been allocated and is divided equally between interface and aircraft areas of concern.

System Performance. The operation of systems associated with acquisition in the ideal concept would have 100-percent performance, which includes reliability, low maintenance, and operability. The ideal system was assigned 100 points, equally divided between interface and aircraft.

Ease of Operation. This factor in the assessment matrix concerns the number of tasks required and the resulting workloads. Included in the rating are factors for operation in day/night conditions and IMC. The ideal system would reduce the number of tasks such that all workloads would be at or below recommended levels under all meteorological conditions. The ideal system would not require ground personnel. The points were equally distributed between ground and aircrews with the ideal rated at 200 points.

System Adaptability. The ideal system could be used on all existing aircraft without modification, and would be capable of interfacing all existing and proposed loads as well as rigging equipment. The total rating points of 100 are equally divided between interface and aircraft.

Operational Safety. The ideal system concept would have no potential hazardous conditions. The results of the Phase I hazard analysis would be used to determine the rating of each concept. The rating points are distributed as follows: 100 maximum for ground crew, 100 maximum for flight crew, and 50 for the aircraft.

Mission Effectiveness. The ideal system would obviously have an effectiveness of 100 percent, which would, therefore, receive maximum points. To provide a finer detailed rating, mission effectiveness of each area of concern is analyzed. The effect on the complete mission is considered. The impact of day/night conditions and IMC is evaluated and their effect on transport is included. The distribution of points is as follows:

Interface	- 50 points maximum
Flight Crew	- 100 points maximum
Ground Crew	- 50 points maximum
Aircraft	- 50 points maximum
TOTAL	- 250 points maximum

Concept Ranking

Each concept was evaluated using the evaluation matrix. The areas of concern were assigned values up to the maximum allocated for each box of the matrix. The scores for each box were then totaled to provide an overall point count for each concept.

Ranking Results. When the total scores for each concept were compared, the order of the following ranking of candidates resulted:

- Nose beam mechanical
- Extendable arm
- Magnetic hookup
- Long line
- Secondary cable
- Cockpit imaging
- Hoist
- Indirect viewing
- Tandem hook beam
- Single active arm
- Dual active arm

Figure 20 presents a summary of the results of the evaluations depicting the relative ranking of each concept to the baseline (existing system) and to the ideal system. The complete analysis, including the detailed evaluations of each concept, is presented in Appendix C.

Ranking Discussion. Ranking results indicated that a relatively simple system providing the flight crew's direct view of the acquisition process could provide significant improvement. By eliminating the ground hookup crew, the problems associated with crew training and safety are eliminated. Due to the small distance that the crew has to view the load, hookup in very marginal conditions is possible, and using night vision goggles, blackout hookups are possible without aircraft modification.

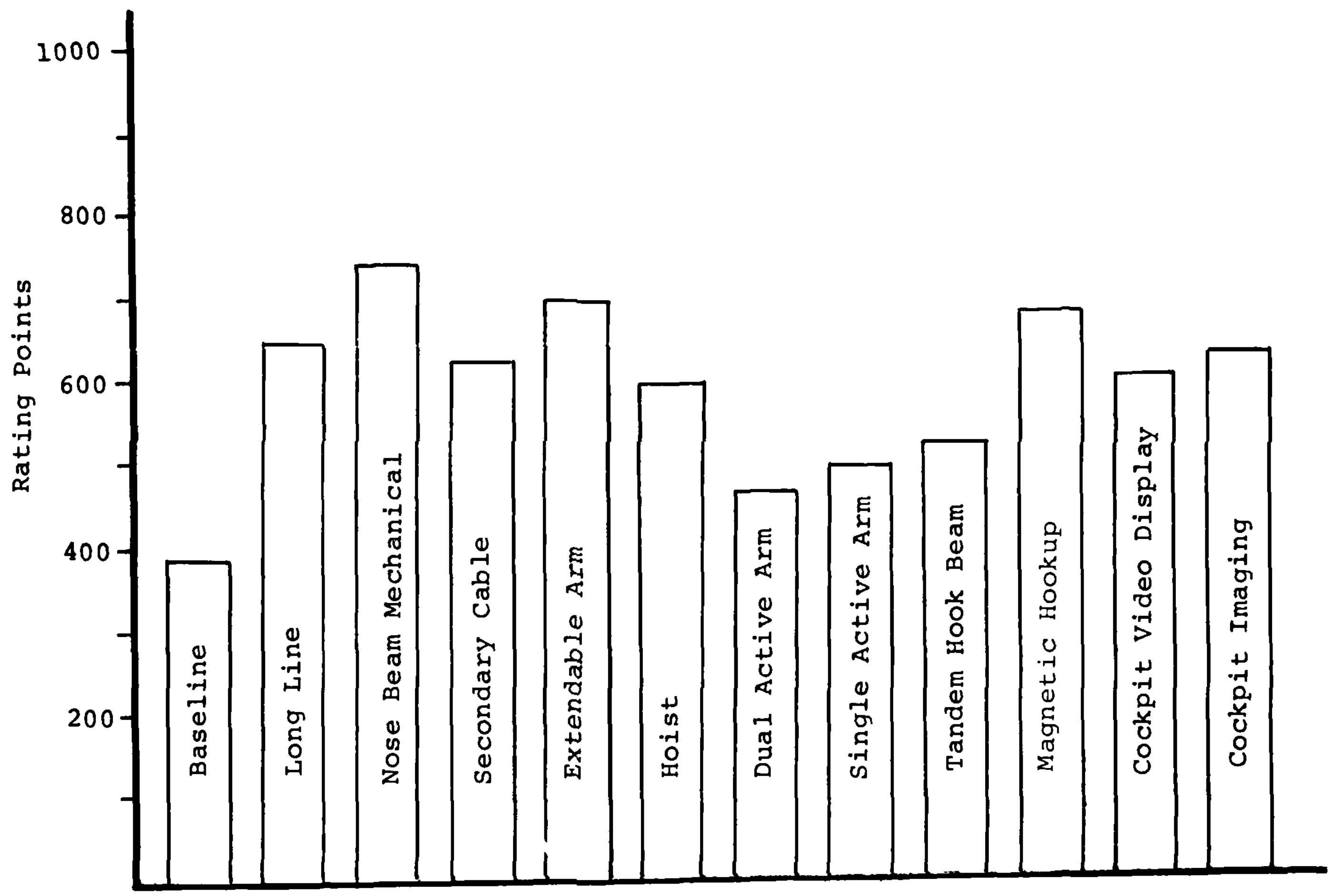

Figure 20. Concept evaluation summary.

Each concept was ranked individually. No attempt was made to optimize concepts. Concepts could be combined and the resulting system would provide significant improvement over an individual concept. An example might be to use dual hoists and cockpit imaging on a CH-47D. The resulting concept would receive a high rating.

CONCLUSIONS

Results of this study indicate that external cargo acquisition will require improvement for expanded night and IMC operations. Increased design consideration of the acquisition phase of external load operations is needed for current operations and will be required for the night/IMC missions. Specific study conclusions are:

- Current helicopters are not capable of safe sustained all-weather external cargo missions.

- Current helicopters are not capable of safe night covert external cargo missions.

- Cockpits are not "Human Factored" for external load operations.

- The success of external load acquisition is dependent on training and experience of ground crews.

- Acquisition improvement will require improved aircraft handling qualities, improved cockpit instrumentation, and load measuring equipment.

- All candidate concepts significantly improved acquisition.

RECOMMENDATIONS

To assure improvements in external load acquisition systems, it is recommended that:

- The following general improvements be incorporated:

  Stability and control augmentation during hover

  Load sensors

  Precise height sensors

  Night blackout cockpits

  Increased ground crew training

- The nose beam acquisition concept be investigated further and developed into a prototype test.

- Cockpit instrumentation requirements for external load acquisition in night and IMC conditions be investigated further.

- Results of this study be analyzed further to determine optimum concept combinations that could be used for acquisition improvement.

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APPENDIX A

MISSION SEGMENTS

The top-level mission phase flow diagram was further subdivided into mission phase segments. Figures A-1 through A-8 detail the mission phases and are in the following sequence:

1.0 Cruise to Pickup Zone
2.0 Approach for Pickup
3.0 Hookup
4.0 Departure with Load
5.0 Transport Load
6.0 Approach with Load
7.0 Release Load
8.0 Departure After Load Release

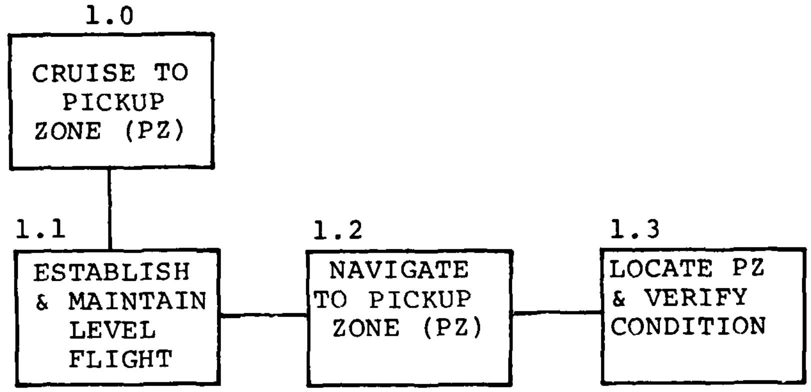

Figure A-1. Cruise to pickup zone.

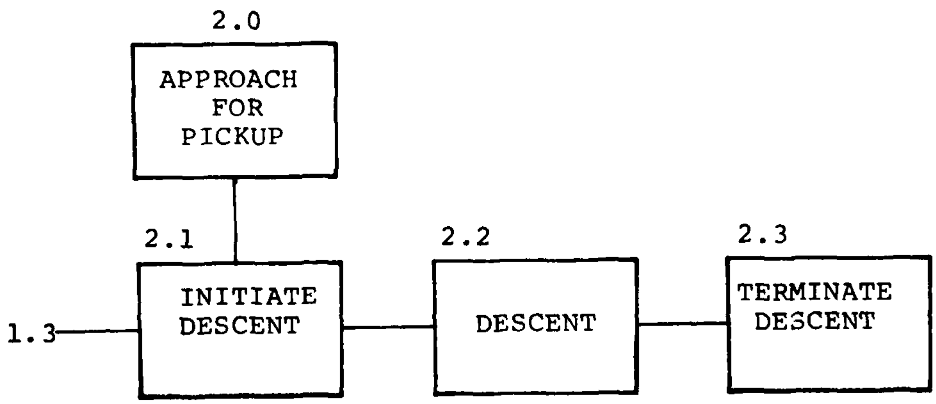

Figure A-2. Approach for pickup.

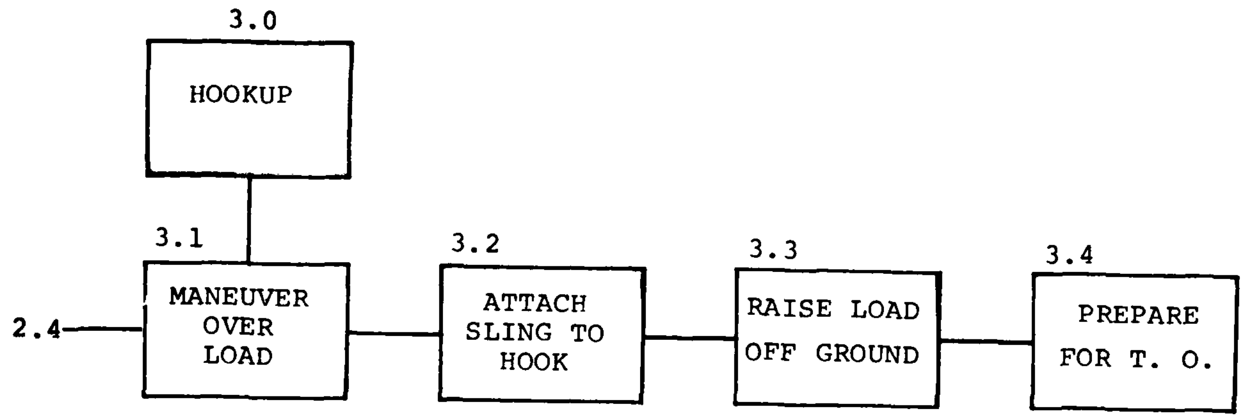

Figure A-3. Hookup.

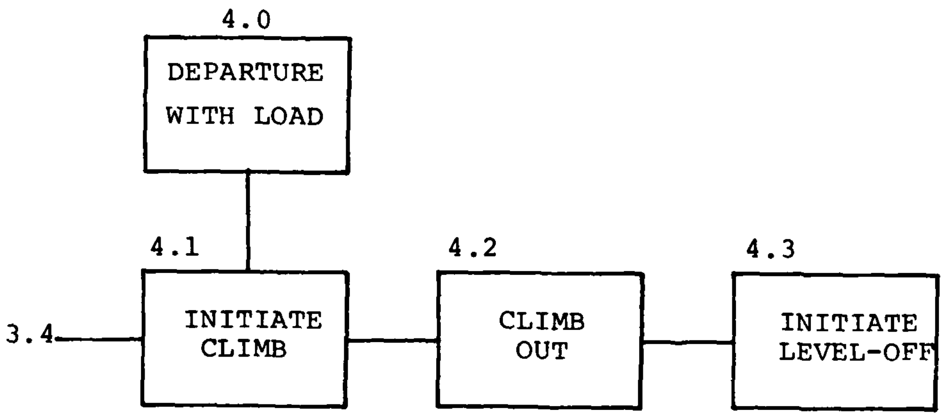

Figure A-4. Departure with load.

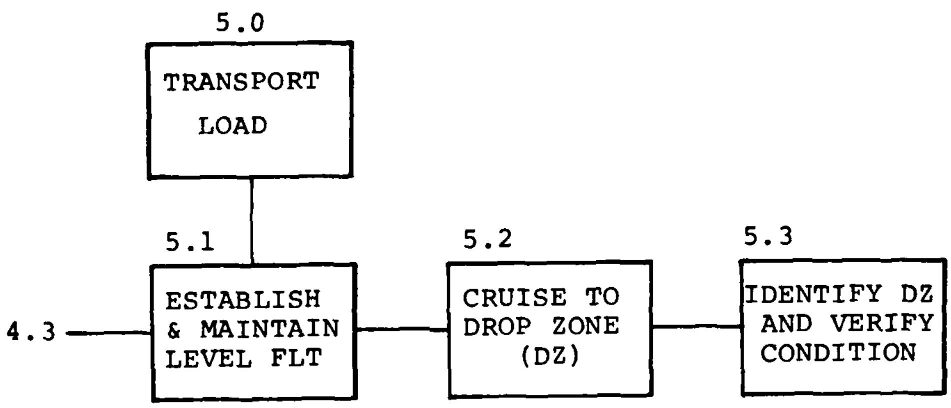

Figure A-5. Transport load.

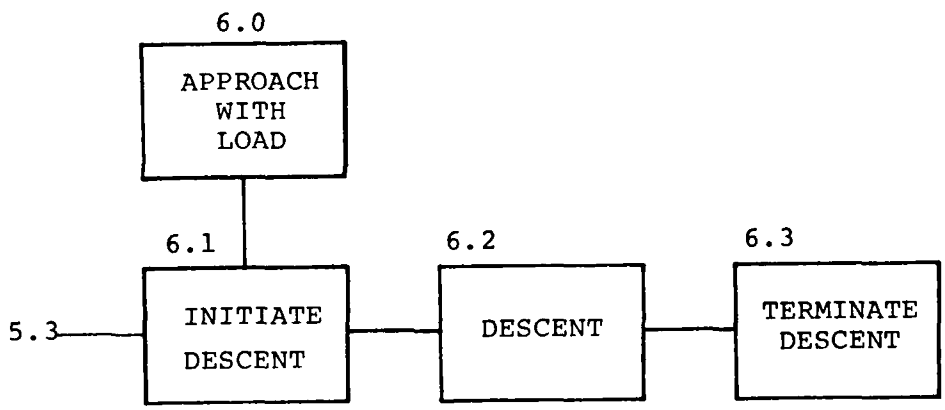

Figure A-6. Approach with load.

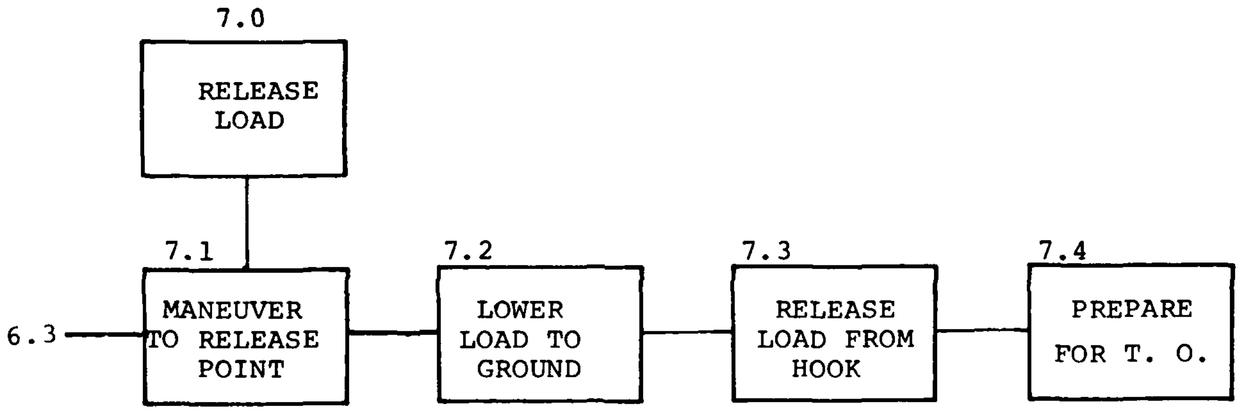

Figure A-7. Release load.

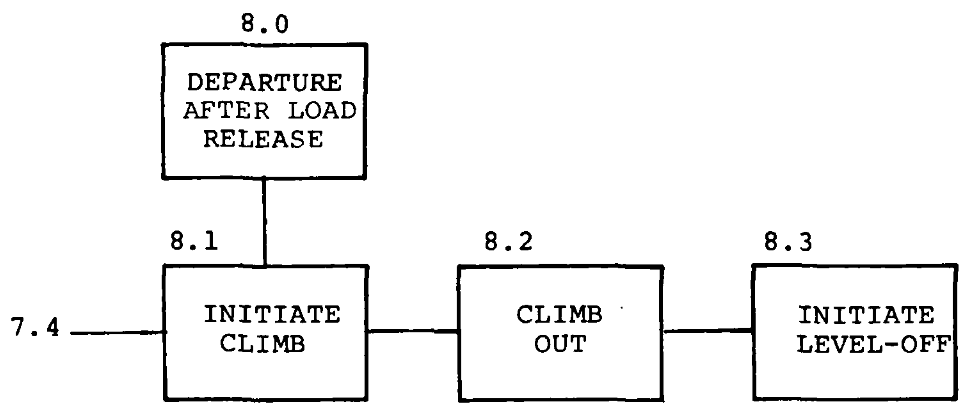

Figure A-8. Departure after load release.

APPENDIX B

EXTERNAL LOAD ACQUISITION STUDY QUESTIONNAIRE

(AND TYPICAL ANSWERS)

GENERAL

1. What is your flight crew rating ?

   Pilot 29, Flight Engineer/Crew Chief 0, Other 0 (Specify)

2. In what type/model/series helicopter do you have the most external load experience ? 12 CH-47; 8 UH-1H; 9 UH-60

3. Have you conducted external load operations at night ? Yes 28 No 1

   (Comments:) ______

4. Have you conducted external load operations in weather (IFR) ?

   Yes 14 No 15

   (Explain:) ______

5. What is your most frequent external load mission ?

   A-22 Bag Loads 3 Howitzers/Guns 5

   Pre-rigged loads 17 Other (4) Mules, jeeps, goats, 1/4 trailors, fuel (Specify)

6. What is your most common hookup method ?

   A. Ground hookup crew 23

   B. Flight crew on ground 3

   C. Flight crew in aircraft 1

   D. Other (Specify:) ______

7. Which of the above methods do you prefer for hookup maneuvering and why ?

	Ground Crew	Flight Crew in A/C
(Discuss)	A - 16 B - 0	C - 10
	No Response - 3	

8. What is the most common method you use to identify the load to be picked up ?

Air/ground communication 3 ; Ground signalman 26 ;

Ground markings ___; Other (Describe) ___

9. In your opinion, what tolerances are required while hovering over the load for normal hookup (hook relative to load) ?

Ft. laterally 2.5 ; Ft. fore and aft 2.0 ;

Ft. vertically 1.0 . (Average response.)

10. What is your time interval to hover over a load for pickup ?

10 Sec Minimum, 30 Sec Average, 60 Sec Maximum (Average response.)

11. Have you ever used mirrors on the nose of the helicopter for hookup ? Yes 4 No 25

Comment: ___

12. From your experience, what percentage of external load operations did you encounter low visibility conditions, such as blowing dust, sand, snow, etc. ? (Average 20% for 20 respondents; 9 respondents had not experienced low visibility conditions.)

13. Referring to #12, what was the average onset level (altitude) of low visibility conditions ? (Discuss) (Average onset was 10 ft. Fifteen (15) respondents expressed no opinion.)

14. Referring to #12, what was the minimum visibility encountered ? (Discuss) (Majority of respondents indicated "0" visibility.

15. If you had a choice in a new external load acquisition system, which of the following would you prefer ?

15 (a) A system where the external load is acquired by the pilot without ground assistance.

14 (b) A system where the external load is acquired with ground assistance.

Why ? (Discuss) ______

16. Rate the following list of equipment or systems, highest (1) to lowest (6), in importance for improved external load operations:

1 Automatic stabilization on aircraft (AFCS)

5 Direct visual reference to hook during hookup.

4 Direct visual reference to load during hookup.

2 Cockpit display of position in relation to load.

3 Cockpit indication of hookup.

6 Other, specify: Load meter (2) (cockpit display of load on hook) Light down on load.

17. In your opinion, what is the most severe problem with external load acquisition ?

Comments:

Assuring that a crew is provided for hookup, the most severe problem would be controllability in crosswind conditions.

- -

Visual reference to the load during hookup.

- -

Accurate positioning of helio over load, thereby creating hazards which may result in injury to personnel, damage to helio or damage to external load.

- -

Debris generated by rotor made it very difficult for ground personnel to hook up load. Not enough use was made of sit-down-hookup method of loading.

- -

Judging which load to carry should ground guide not be available.

- -

The most severe problem with external load acquisition is visibility reduction by blowing dust, sand or night external loads.

- -

Crew coordination and training during the restricted period allocated for training. Time does not allow the pilots and crew chiefs to become as familiar with the individual peculiarities of one another.

- -

Training of both flight and ground crews.

- -

17. (Continued)

Comments:

A hook that is in good operating condition. A hookup man on the ground that is not afraid of the helicopter.

- -

Night operations in tactical environment necessitating the negative use of aircraft landing lights during low levels of ambient light illumination.

- -

Ability to make small corrections with aircraft in unstable conditions - gusty wind/unstable aircraft.

- -

With adequate training and experience, there are no serious problems. It becomes a very routine, safe operation. Under adverse visibility conditions, the most severe problems are related ground visual reference and obstacle clearance.

- -

Centering the A/C above the load.

- -

Centering the aircraft over the load.

- -

Dust - poorly trained hookup men.

- -

Unbalanced or over gross load.
Sling failure.
Aircraft failure.

- -

Cannot see load being hooked up.

- -

Unstable load sling.

- -

Maintaining constant point hover.

- -

Ground acquisition (training/lack of pilot acquisition).

17. (Continued)

Comments:

Inexperience of ground personnel. Fixed hook position rather than one that swivels.

- -

Communication between pilot and observer.

- -

Ground signalman.

- -

A poorly stabilized aircraft like the UH-1H

- -

18. From your experience and knowledge of the mission, what suggestions and/or concepts would you recommend for improved external load operations, and in particular, under poor visibility conditions, such as blowing sand, dust, snow, and at night.

Comments:

Mission plus display equipment of aircraft and load.

- -

Some sort of range finding and position fixing means, possibly combined with hover autopilot.

- -

Stability equipment is almost necessary, at worst it's highly desirable due to the potential for catastrophic disorientation within close proximity to the surface.

- -

Four bladed system, two hookups, radar alt.

- -

Load acquisition from cockpit

- -

Max use of sit-down-hookup to avoid extended hover and rise associated with poor visibility hover, especially dust and snow.

- -

Method by which a load could be acquired and hooked up without assistance by ground crew. This would require some type of cockpit display to show position of aircraft in relation to load and hook/load status (including load weight). This system could be augmented by a landing approach system (mobile VORTAC, TILS) and should include a hover coupler.

- -

Use longer sling to keep pilot's visibility above and over the top of the blowing sand with a grappling hook or drop a grappling hook through the floor to the ground, hook the sling to it, crew chief pulls the hook attached to a cable with the sling's doughnut ring attached to the aircraft, crew chief hooks doughnut ring to the aircraft cargo ring.

- -

18. (Continued)

Comments:

Any visual devices would be a distraction; ideally, the pilot's attention is focused outside of the aircraft. If a small transmitter was incorporated in the hookup ring the pilot could receive audio cues with regard to his position over the load. If distinctively different tones were used to indicate fore, aft, left, right, up or down, the pilot could, with minimal practice, pick up loads in marginal weather with no crew at all.

Weight/torque gauge on aircraft hook.

Aircraft stabilization would be extremely helpful, as would loadmaster override on flight controls. Another area needing consideration is organization and layout of the sling load, pickup area (e.g. clearance, reference markings, lighting).

Automatic hover and for load acquisition to minimize exposure time in such operations. Blowing debris creates a visual means of detection by enemy. Night and weather operations are severely restricted by a lack of radar altimeter and autopilot to reduce fatigue induced by such precise operations.

At night side lights for visual cues (peripheral vision) forward light blinds ground guides.

Light inexpensive clamp on devices to loads to improve aerodynamic qualities of load.

Goggles on ground handling personnel.

Automatic stabilization to include some kind of hover altitude hold with an automatic go-around capability that would fly the aircraft out of the IFR condition.

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18. (Continued)

Comments:

Automatic stabilization on aircraft and cockpit display in relation to load.

Discontinue external loads if conditions are unfavorable.

A system for better ground reference and some type of better load centering.

More coordination on the ground with the troops.

Everything on the UH-60 plus a light that shines straight down beside the hook.

Avoid if possible

APPENDIX C

DETAILED CONCEPT EVALUATIONS

Each concept was evaluated using the evaluation matrix. Point ratings for each box of the matrix were subjectively estimated based on a range of point ratings. The sub-factors and point rating ranges for each factor of merit are summarized in Table C-1.

TABLE C-1. EVALUATION TABLE

Factors of Merit	Sub Factor	Point Rating Range
Simplicity of Design		
• Interface related	Complexity	1 point for very complex to 10 points for very simple.
	Weight	1 point for very heavy to 10 points for 0 weight.
	Development risk	1 point for high risk, long development time, not current technology to 10 points for existing low risk "off-the-shelf" equipment.
	Cost	1 point high equipment costs to 10 points for 0 or very low cost.
• Aircraft	-	(Same as Interface)
System Performance	-	1 point for poor operability to 50 points for exceeding performance goals.
• Ground Crew	No. of crew required	Range 1 point for more than 3 to 50 points for 0 crew.
	Training	Range 1 point for extensive training required to 25 points for no training required.
	Rigging time	Range 1 point for longer time than present to 25 points for no rigging required.

TABLE C-1. (continued).

Factors of Merit	Sub Factor	Point Rating Range
• Flight Crew	Tasks	1 point for large increase - 10 points same as existing to 20 points for large reduction in tasks.
	Workload	Day/1 point for 100% or more crew workload to 20 points for all crew workloads below 70%. Night/same as day except range is 1 to 30 points. IMC - Same as night.
System Adaptability • Interface	-	1 point for requiring all new ground equipment to 50 points for new equipment requirements.
• Aircraft	-	1 point if all aircraft require major modification to 50 points if concept is adaptable to all aircraft without modification.
Operational Safety • Ground and Flight Crew	-	1 point for increase in hazards and severity to 100 points for all hazard reduction to no worse than marginal.
• Aircraft	-	1 point for increase in hazards and severity to 50 points for reduction of all hazards and severity to no worse than marginal.

TABLE C-1. (concluded).

Factors of Merit	Sub Factor	Point Rating Range
<u>Mission Effectiveness</u> • Interface, ground crew and aircraft	-	1 point for less than 10% effectiveness to 50 points for 100% effectiveness
• Flight crew	-	Day - 1 point for less than 10% effective to 20 points for 100% effective. Night and IMC - 1 point for less than 10% to 40 points each for 100% effectiveness.
• Aircraft	-	Day - 1 point for less than 10% to 50 points for 100% effectiveness.

6
F

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	46			46	92
System Performance	25			25	50
Ease of Operation		40	31		71
System Adaptability	25			1	26
Operational Safety		25	25	10	60
Mission Effectiveness	10	25	31	16	82
TOTAL COUNT	106	90	87	98	381

Figure C-1. Baseline evaluation.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	42			40	82
System Performance	40			40	80
Ease of Operation		45	52		97
System Adaptability	40			40	80
Operational Safety		60	75	35	170
Mission Effectiveness	40	30	45	31	146
TOTAL COUNT	162	135	172	186	655

Figure C-2. Long line.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	32			41	73
System Performance	35			30	65
Ease of Operation		55	55		110
System Adaptability	25			30	55
Operational Safety		100	90	40	230
Mission Effectiveness	40	50	65	34	189
TOTAL COUNT	132	205	210	175	722

Figure C-3. Nose beam mechanical acquisition.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	34			33	67
System Performance	35			30	65
Ease of Operation		55	40		95
System Adaptability	25			30	55
Operational Safety		100	50	30	180
Mission Effectiveness	40	35	60	26	161
TOTAL COUNT	134	190	150	149	623

Figure C-4. Secondary cable hookup.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	25			25	50
System Performance	25			25	50
Ease of Operation		55	55		110
System Adaptability	25			30	55
Operational Safety		100	90	40	230
Mission Effectiveness	40	50	70	39	199
TOTAL COUNT	115	205	215	159	694

Figure C-5. Extendable arm acquisition.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	16			21	37
System Performance	20			20	40
Ease of Operation		40	49		89
System Adaptability	40			1	41
Operational Safety		75	75	35	185
Mission Effectiveness	35	50	75	39	199
TOTAL COUNT	111	165	199	116	591

Figure C-6. Dual hoist (CH-47).

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	16			21	37
System Performance	15			20	35
Ease of Operation		40	35		75
System Adaptability	25			10	35
Operational Safety		35	35	15	85
Mission Effectiveness	25	35	78	39	177
TOTAL COUNT	81	110	148	105	444

Figure C-7. Dual active arm (CH-47).

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	20			25	45
System Performance	20			25	45
Ease of Operation		40	35		75
System Adaptability	25			30	55
Operational Safety		35	35	15	85
Mission Effective-ness	25	35	78	39	177
TOTAL COUNT	90	110	140	134	482

Figure C-8. Single active arm.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	34			40	74
System Performance	35			30	65
Ease of Operation		38	25		63
System Adaptability	25			30	55
Operational Safety		25	25	10	60
Mission Effective-ness	75	25	55	39	194
TOTAL COUNT	169	88	105	149	511

Figure C-9. Tandem hook beam.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	40			40	80
System Performance	38			38	76
Ease of Operation		41	47		88
System Adaptability	5			40	45
Operational Safety		100	75	35	210
Mission Effectiveness	35	40	80	27	182
TOTAL COUNT	118	181	202	180	681

Figure C-10. Automatic magnetic hookup.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	46			25	71
System Performance	25			40	65
Ease of Operation		40	65		105
System Adaptability	25			30	55
Operational Safety		25	75	30	130
Mission Effectiveness	10	35	75	39	159
TOTAL COUNT	106	100	215	164	585

Figure C-11. Indirect aided viewing.

EXTERNAL LOAD EVALUATION MATRIX

FACTORS OF MERIT (QUALITY)	AREAS OF CONCERN				TOTAL COUNT
	Interface Related	Ground Crew/ Load Related	Flight Crew/ Mission Related	Aircraft Related	
Simplicity of Design	46			25	71
System Performance	25			40	65
Ease of *Operation*		40	75		115
System Adaptability	25			30	55
Operational Safety		25	75	30	130
Mission Effective-ness	10	35	85	40	170
TOTAL COUNT	106	100	235	165	606

Figure C-12. Cockpit indication and imaging.

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